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CONTENTS

The Masses of Atoms and the Structure of Atomic Nuclei. . KENNETH T. BAINBRIDGE 509

On Electron Optics . . . . . V. K. ZWORYKIN 535

Grain Boundary Effects as a Factor in Heterogeneous Equilibrium of Alloy Systems. ARTHUR PHILLIPS AND R. M. BRICK 557

The Structure of Unimolecular Films. II. Surface Films of Proteins. RUSSEL J. FOSBINDER AND ANNA E. LESSIG 579

Secondary Emission of Electrons from Molybdenum . . . . . PAUL L. COPELAND 593

Notes from the U. S. Bureau of Standards 599

The Franklin Institute Notes 609

Book Reviews 613

Publications Received 616

Current Topics 556, 578, 592, 618

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INDEX TO ADVERTISERS

PAGE

American Telephone and Telegraph Co. .....Third cover page

Commercial Photo Engrav. Co. Fourth cover page

Dreka Co. iv

Electrical Testing Laboratories . iv

Fidelity-Philadelphia Trust Co. . iii

FRANKLIN INSTITUTE, Awards of vi

FRANKLIN INSTITUTE, Membership, Terms and Privileges.... vii

FRANKLIN INSTITUTE, Pamphlet Reprints of Lectures and Other Contributions ...Fourth cover page

Girard Trust Co. ..Fourth cover page

PAGE

Glynn Kohler Printing Co. iv

Hagan, John, & Co. v

Haynes & Fehr iv

Journal of THE FRANKLIN INSTITUTE, March, 1926, April, 1929, March, 1930, and Sept., 1930 .....Second cover page

Katz, George, & Co. Fourth cover page

Lancaster Press, Inc. v

Sadtler, Samuel P., and Son, Inc. iv

Smith, Haseltine, & Co., Inc. Second cover page

United Engineers & Constructors, Inc. ii

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THE MASSES OF ATOMS AND THE STRUCTURE OF ATOMIC NUCLEI.

BY

KENNETH T. BAINBRIDGE,

of the Bartol Research Foundation of the Franklin Institute.

BARTOL RESEARCH FOUNDATION
Communication No. 73.

The atomic nucleus does not lend itself kindly to study. It is remote and has been inaccessible to the prying curiosity of investigators until the beginning of this century. I am going to describe one method of study which, chiefly in the hands of Dr. F. W. Aston, has yielded a wealth of important information and has contributed much to our knowledge of atoms. I have in mind experiments which permit the investigator to deal with atoms individually and compare their masses with the highest accuracy. Before describing these experiments it is necessary to consider the nature of the atom itself.

The Rutherford-Bohr model of the atom, unchanged by any recent advances in theoretical physics in features essential to this discussion, pictures a heavy central nucleus, positively charged, surrounded by negative electrons. The atomic number, or ordinal number of an element in the periodic table, is equal to the net positive charge of the nucleus which determines the number of external electrons in the neutral atom and the chemical properties of the atom.

A development which accompanied the growth of the nuclear theory of the atom was the discovery of isotopes. Elements non-separable by chemical means but differing in the

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physical properties of mass or radioactivity were known to chemists as early as 1906. In 1913 Sir Frederick Soddy suggested the word isotope to denote atoms of this class which occupy the same place in the periodic table of the elements.

An atomic nucleus containing twenty protons and ten electrons will have an atomic number 10 corresponding to its net positive charge, and the ten surrounding electrons of the neutral atom will determine the chemical nature of that element, in this case neon. The addition of one proton and one electron, or one neutron, to the nucleus will result in an isotope of mass 21 identical in chemical properties with the first. An indefinite number of isotopes are possible theoretically for any element. Each isotope of any element is a distinct and separate nuclear species. Isotopes were first noticed among the radioactive elements but it was Aston who demonstrated that isotopy was a general property of all elements radioactive or not.

Before the discovery of the isotopes Sir J. J. Thomson had shown that electrons, the units of negative electricity, had the same specific charge e/m, the same charge e and the same mass m independent of their origin, whether obtained from gases or solids, metals or non-metallic elements. The mass of the electron was found to be only 1/1846 of the mass of the lightest known positive entity, the hydrogen nucleus. The remainder of the atom, the heavy positive nuclei, were known from chemical atomic weight determinations (combining weights) to vary widely and values occurred of 35.45 for chlorine, 10.82 for boron, 6.94 for lithium referred to oxygen arbitrarily selected as 16. No simple divisor exists for these values. Obviously the universal sameness of the negative units of electricity was not shared by the positive parts of atoms.

Over a century ago Dalton had suggested that atoms of the same element are similar to one another and equal in weight. On this basis all of the atoms of neon for example would have a mass 20.2 referred to oxygen taken as 16 for a standard. On the other hand Prout had suggested that atoms of the elements were all aggregates of a single simple building stone which in its most elementary form was identical with hydrogen. On this basis the atomic weights of elements would be whole numbers when referred to hydrogen. Prout's

hypothesis was abandoned as soon as more accurate atomic weight determinations showed that fractional atomic weights existed. It is not surprising that Dalton's theory was accepted as a working hypothesis and that atomic weights or combining weights of atoms were looked upon as the relative weights of the atoms themselves.

Further experiments of J. J. Thomson in 1912 suggested very strongly that neon atoms did not have masses of 20.2 referred to oxygen as 16 but that two kinds of neon existed, one of mass 20 and another of mass 22 which occurred in the abundance ratio 10/1 approximately. In 1919 Aston by means of an instrument which he had developed, obtained definite proof that there were at least two isotopes of neon. This was the first of a long series of brilliant analyses of the elements which showed that isotopy was a general property of the elements, not confined to those that are radioactive.

The most important result of Aston's proof of the general isotopic nature of the elements was a great simplification of the ideas of the constitution of matter. The weights of all the atoms examined except hydrogen were found to be whole numbers to a very close approximation when referred to one sixteenth of the mass of the oxygen atom O^{16}. Atoms of the chemical elements were taken to be aggregations of units of positive and negative electricity of which the negative unit was the electron, the positive unit the proton or hydrogen nucleus. The loss of mass occasioned in this hypothetical building process will be dealt with later.

Fractional atomic weights were thus easily explained. For example, the atomic weight of chlorine 35.46, represented the average weight or combined effect of two isotopes of masses 35 and 37, with Cl^{35} about three times more abundant than Cl^{37}.

In the nineteenth century Newlands, Mendeléeff and other chemists searching for relationships among the elements found that when they were arranged in order of increasing atomic weights certain periodicities appeared in their chemical properties which led to the development of the periodic table. In a few cases the periodicities did not correspond to the order of increasing atomic weights. From a consideration of the chemical properties, argon should have appeared before

potassium in the periodic table but the atomic weight of potassium was less than that of argon. Similar inversions were observed for cobalt and nickel, and for tellurium and iodine. With the discovery of isotopes it has been possible to account for these anomalous weights. For instance in the case of potassium of atomic weight 39.10 and argon of atomic weight 39.93, potassium of atomic number 19 is composed mainly of an isotope of mass 39 and a small amount of an isotope 41, and argon of atomic number 18 is chiefly A^{40} with a small amount of A^{36}.

The chemical identity of isotopes precludes the use of chemical methods for their separation and examination. Minute differences do occur in the chemical properties of some isotopes but these differences only reach an appreciable magnitude in the case of the two isotopes of hydrogen. In general then other methods must be used. The most versatile methods of investigation of isotopes were made possible by the fact that charged particles can be deflected by the action of electric or magnetic fields. By successive or joint application of electric and magnetic fields to a beam of heterogeneous ions the beam can be separated into many beams each with its characteristic ratio of mass to charge m/e.

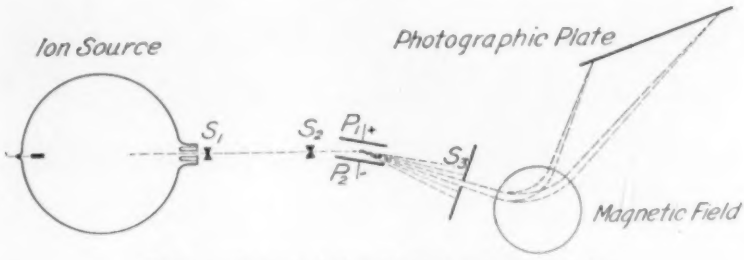
I have here an apparatus which produces a beam of charged particles, for convenience they are electrons in this case, which traverse the region between two plates. When a difference of potential is applied to the plates the electrons are deflected as shown and the amount of deflection is a simple function of the energy of the electrons and is independent of their mass or charge. The amount of deflection for a given deflecting field is inversely proportional to the energy of the beam of charged particles. (Demonstration.)

In this second apparatus a beam of electrons is acted upon by a uniform magnetic field. Here all particles of the same charge and momentum describe the same circular path. The force on the moving charge Hev produced by the magnetic field is balanced by the centrifugal force mv^2/R. The force of the magnetic field on the rapidly moving charged particle confines it to a circular path not unlike the same function performed by a string fixed at one end and tied at the other to a whirling weight. The radius of curvature of the beam of

charged particles is equal to mv/eH where m, v, and e are the mass, velocity, and charge of the particle and H is the strength of the magnetic field. (Demonstration.)

Figure 1 is a schematic representation of the apparatus developed by Aston which allows one to compare the masses of atoms. Gas, or vapor of the material to be examined, is introduced into a discharge tube where an electrical discharge is produced by application of a high potential between the anode and cathode. The action of the discharge is to remove one or more external electrons from the outer structure of the atoms and then endow the resultant ions with kinetic energy. The slits S_1 and S_2 collimate a ribbon-like beam of the rapidly moving ions. The beam of ions may be said to be composed of "mass-rays," because the mass of the atoms is decreased but

FIG. 1.



Diagrammatic representation of Aston's mass-spectrograph.

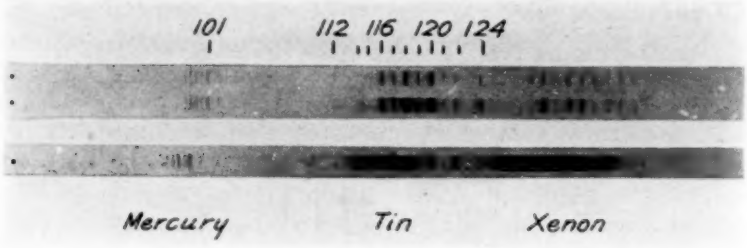
slightly and by a known amount by the loss of the electrons which took place in the discharge tube.

The beam issuing from slit S_2 is subjected to the deflecting action of an electric field between the plates P_1 and P_2 and a slit S_3 selects out mass rays within a small range of energies. Then the rays are introduced into a uniform magnetic field where the rays are deflected in the opposite direction. This is one of the many ingenious features of the apparatus as it permits a beam of ions of the same mass to charge ratio m/e to be brought to a focus on a photographic plate as shown, even though the spread in energy of the ions issuing from slit S_3 may vary over a considerable range. The heavier ions are deflected least and impinge on the far end of the plate, while progressively lighter ions are focussed further to the left.

When the photographic plate is developed black lines appear corresponding to the point of impact of the ion ribbon beams.

Figure 2 [1] is a reproduction of three remarkable mass spectra of Aston's which show the elements tin, xenon, and mercury resolved into their separate isotopes. The striking similarity in appearance of the mass lines to lines of optical spectra make the term mass-spectrograph an apt description of Aston's instrument. Eleven isotopes of tin are discernible ranging in mass from 112 to 124. Some of the nine isotopes of xenon are recorded, the more prominent lines are 129, 132, 131, 134, 136, 128 and 130. The other lines are mercury isotopes photographed in the second order, that is the mercury atoms had lost two electrons so that the effective ratio of mass to

FIG. 2.



Mass-spectra of tin, xenon, and mercury photographed by Aston.

charge is halved. The mass spectrograph compares the ratio of mass to charge of different elements. The standard of reference is the oxygen isotope O^{16}.

Figure 3 is a spectrum of bromine and its hydrides with second order mercury present too.

A mass-spectrograph performs three major functions:

1. Determination of nuclear species and the isotopic constitution of elements.

2. Determination of the relative abundance of the isotopes of specific elements.

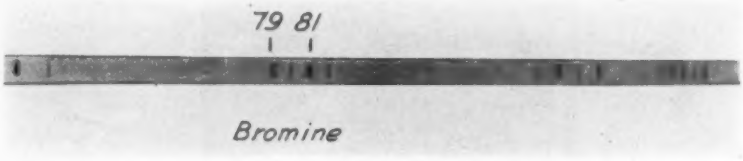
3. Accurate measurement of the masses of atoms.

[1] All of the mass-spectra illustrated in this article are reproduced in their natural size. I am greatly indebted to Dr. Aston for copies of his mass-spectra, a few of which are reproduced.

By virtue of the ability of a mass-spectrograph to separate and deal with individual atoms independently of their chemical nature one may determine what nuclei exist. There is at present no comprehensive theory of the structure of atomic nuclei but when that development does arise the theory must be able to explain why tin for example, has the eleven isotopes included in the spectra of Fig. 2, and why tin isotopes of mass greater than 124 or less than 112 do not occur. Aston has examined about sixty-five of the non-radioactive elements and some 180 atomic species have been discovered.

Over a limited range the photographic blackening produced by the impact of ions on a photographic plate is proportional to the number of ions which struck the plate. The relative abundance of the isotopes of an element may be determined

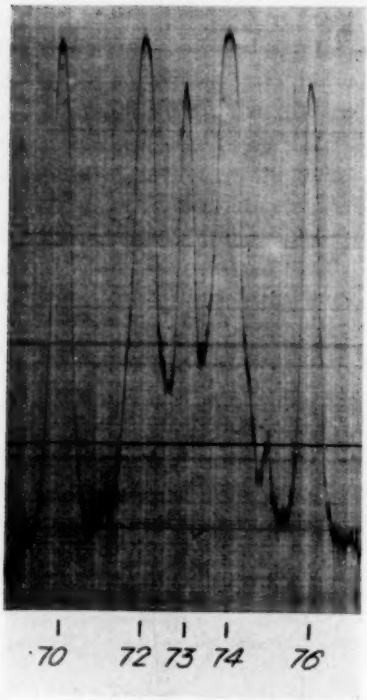
FIG. 3.



Mass-spectrum of bromine isotopes and their hydrides (Aston).

photometrically from the mass-spectrum of the isotopes. Figure 4 is a reproduction of a recording microphotometer record of the blackening of a plate by the isotopes of germanium. The higher peaks indicate darker lines and so more abundant isotopes than the lower peaks. From a record of this type the relative abundance of the isotopes may be derived. If the masses of the isotopes and their relative abundance are known, one may obtain the atomic weight of the element. Figure 5 is a spectrum photographed by Aston which includes the six known isotopes of krypton and the two isotopes of bromine. The atomic weight of krypton which Aston obtained by this method has proved to be more accurate than previous determinations. Early results for beryllium, boron, krypton, xenon, and antimony all gave values for the atomic weights at variance with the chemically determined atomic weights accepted at that time by the

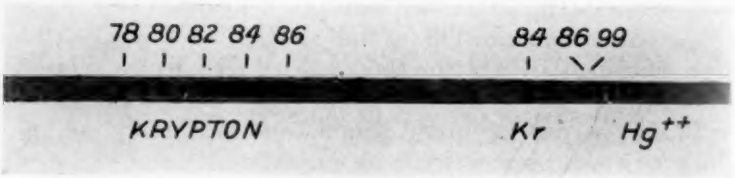
FIG. 4.



Microphotometer record of a spectrum of the isotopes of germanium.

International Atomic Weight Committee. It is one more tribute to the skill of Aston that the corrected values from more recent determinations by chemical means are now in close agreement with the mass-spectrograph values he obtained.

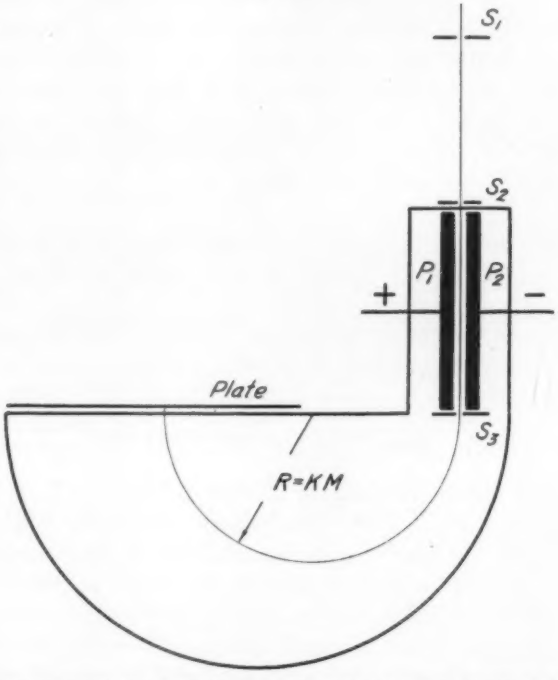
FIG. 5.



Mass-spectrum of krypton and bromine (Aston).

Following the construction of an improved mass-spectrograph in 1925 Aston was able to compare the masses of atoms to an accuracy approaching one part in 30,000. These extremely accurate mass measurements, taken in conjunction with the results of disintegration experiments, are of great importance in the study of the relationship between mass and energy, and as an aid in the theoretical treatment of the structure of the nucleus.

FIG. 6.



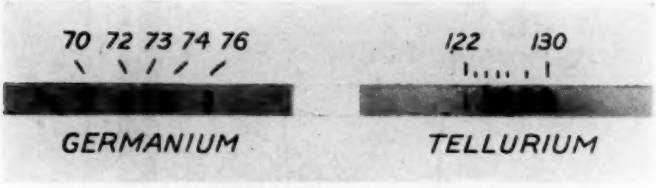
Diagrammatic representation of the mass-spectrograph at the Bartol Research Foundation.

The type of mass-spectrograph in use at the Bartol Research Foundation of the Franklin Institute works on a principle different from that of Aston's. Figure 6 is a schematic representation of the mass-spectrograph. A beam of ions, produced by an electrical discharge in a spherical or cylindrical discharge tube is collimated by slit S_1 and then is introduced through slit S_2 into a "velocity-selector." Ions which

traverse this section of the apparatus without deflection, have a velocity $v = (X/H)$ within narrow limits, where X is the electric field intensity between plates P_1 and P_2 and H is the magnetic field intensity perpendicular to the electric field. The ions which emerge from slit S_3 at the far end of the velocity selector are introduced into a uniform magnetic field, the "camera" section of the apparatus, and are incident on the surface of a photographic plate after describing a circular path for 180°. The radius of curvature of an ion beam $R = (mv/eH)$ is directly proportional to the mass of the ions, as H is maintained constant in value, v is fixed by the velocity selector, and e, the charge on an ion, is constant.

Among the spectra secured with this instrument are two reproduced in Fig. 7. One shows the isotopes of germanium

FIG. 7.



Mass-spectra of germanium and tellurium.

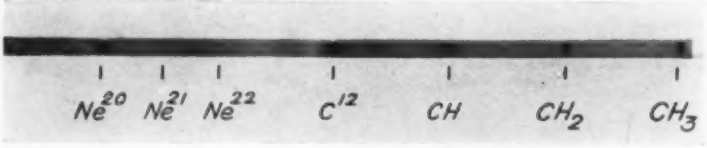
which gave the densitometer record of Fig. 4. The tellurium spectrum is one which was used, together with Aston's results for this element, to determine the atomic weight. The value 127.58 for tellurium secured in this way has since been confirmed by chemical means which gave the value 127.587. If the elements in the periodic table were arranged in order of increasing atomic weights, tellurium would appear after iodine of atomic weight 126.92, instead of before iodine as required by its chemical properties. The preponderance of the heaviest isotopes of tellurium 128, and 130, has raised the average weight above that of iodine.

Mass-spectra have been secured for the elements lithium, sodium, chlorine, argon, potassium, titanium, selenium, bromine, krypton, cadmium, cæsium and mercury which have served to confirm Aston's analyses of these elements.

In the cases of zinc and germanium the previously accepted analyses were found to include more isotopes than actually exist. The occasional unavoidable presence of hydrogen in the discharge tube sometimes results in the formation of hydrides of an element. The addition of a hydrogen atom to an isotope furnishes another ion of mass one unit greater which may be mistaken for an isotope of the element or may invalidate the determination of the relative abundance of two actual isotopes differing in mass by one unit. This most recent analysis confirmed the earliest analysis of zinc made by Professor A. J. Dempster who in 1920 and 1921 analyzed lithium, magnesium, zinc, calcium and potassium.

More spectra of neon than of any other element have been taken at the Bartol Research Foundation, since it has been a general practice to photograph the neon isotopes as the last

FIG. 8.



Second-order spectrum of neon.

spectrum taken on a plate in order to check the performance of the instrument before inserting a new plate for another series of photographs. It was soon apparent that the neon isotope of mass 21, if it existed at all, was much less abundant than 2 per cent., the figure generally accepted.

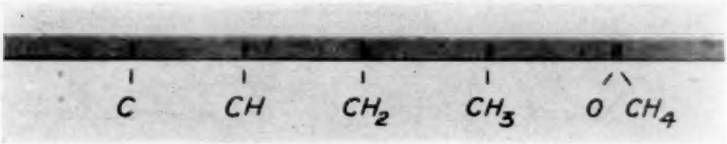
Figure 8 is a reproduction of the three known isotopes of neon photographed in the second order. From the spectra of this type the abundance of neon 21 was measured approximately as 0.6 per cent. of the abundance of both the other isotopes neon 20 and neon 22. The neon isotopes were photographed in the second order (doubly-ionized) because the most successful method of avoiding the effect of hydrides in the apparatus is to deal with multiply-charged ions. Multiply-charged molecules occur but seldom so that one may be reasonably sure of dealing with atomic ions when second-order spectra are photographed.

Dr. Walker Bleakney has been working independently on the problem of the relative abundance of the isotopes of neon with an apparatus better suited for accurate measurements of this type. His more accurate results indicate somewhat less neon 21 than I have found.

The results I have just mentioned are representative of the first two major functions of the mass-spectrograph, (1) the determination of atomic species and (2) measurements of the relative abundance of the isotopes of specific elements.

The third function of the mass-spectrograph is the accurate measurement of the masses of atoms. For convenience, and as chemical combining weight determinations are referred to oxygen, the isotope of oxygen, O^{16}, was selected by Aston as the standard of mass. The measurement of the mass of an atom as performed with the mass-spectrograph is in

FIG. 9.



Mass-spectrum of the oxygen-methane doublet and the lines of carbon and its hydrides (Aston).

reality a comparison of its mass to charge ratio m/e with that of O^{16}. The charge e is equal to the electronic charge or an integral multiple of it which is easily determinable. This charge is taken to be constant, as no evidence has ever appeared to the contrary, so that the comparison of m/e of ions amounts really to the comparison of the masses of the atoms after the small necessary correction has been made to take account of the mass of the one or two external electrons lost from the atom when the ion was formed.

Figure 9 is a spectrum of carbon and its hydrides taken by Aston. The two lines on the right are oxygen and methane, CH_4. The mass of the oxygen atom is exactly 16, the mass of the methane molecule is 16.0350, chiefly owing to the excess mass of the four hydrogen atoms. The difference in mass amounts to only one part in about 500. The probable error

in the measurement of the mass of methane from this and similar spectra was about one part in 30,000. The power of the mass-spectrograph method for accurate measurement of small masses is apparent from a consideration of what takes place when the spectrum is photographed. The amount of material which struck the photographic plate could not be as great as a millionth of a millionth of an ounce. The weight of a methane molecule is only a millionth of a millionth of the total material which struck the photographic plate and yet it is possible to attain an accuracy of one part in 30,000 in comparing the masses of oxygen and methane.

Figure 10 shows a comparison of the masses of helium and hydrogen made at the Bartol Foundation. Doubly-ionized helium was compared with the singly-ionized hydrogen diatomic molecule. If helium had exactly the same mass

FIG. 10.

Mass-spectrum of the He^{++} – H_2^{1+} doublet and triatomic hydrogen H_3^{1+}.

as four hydrogen atoms only a single line would appear on the left of the plate under the conditions of the experiment. The separation of the lines found experimentally gives a measure of the difference in mass occasioned in the coalescence of four protons and electrons or four hydrogen atoms to form one helium atom. The difference amounts to about 0.029 mass units equivalent to 27 million electron-volts energy lost in the hypothetical process of the formation of helium. The mass of hydrogen measured from spectra similar to Fig. 10 was 1.007775 ± 0.000035 when referred to the mass of oxygen O^{16}. The probable error in the determination of the relative masses of hydrogen and helium was only one part in a hundred thousand. Accuracy as high as this has only been obtained in this one most favorable case with existent mass-spectrographs.

There are two isotopes of hydrogen, the existence of the heavier isotope H^2 having been demonstrated last year by Professor H. C. Urey, Dr. W. Brickwedde, and Dr. J. M. Murphy. Dr. Bleakney confirmed the discovery shortly afterwards and showed that ordinary hydrogen contains about 30,000 atoms of the light hydrogen H^1 to every atom of the heavy hydrogen H^2, and that the mass of H^2 must be greater than 2.008. Professor Urey and Dr. Bleakney very kindly sent some concentrated hydrogen to the Bartol which contained one atom of H^2 to every 1050 of the light hydrogen atoms. With the aid of the data secured by Dr. Bleakney it was possible to consider various methods for measuring the mass of H^2.

Figure 11 is a spectrum containing the lines H_3^{1+} on the left and on the right the helium line with an adjacent line on the

FIG. 11.

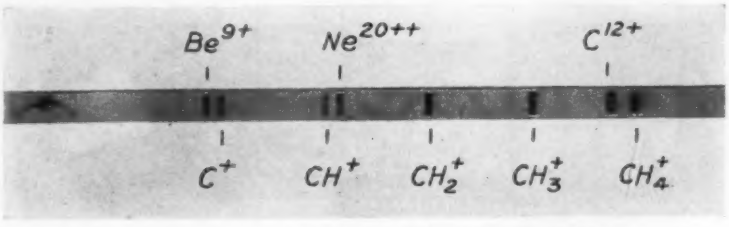
Mass-spectrum of the $He^+ - H_3^1$ H^{2+} doublet and triatomic hydrogen H_3^{1+}.

side of heavier masses. The position of this line corresponded to a mass of 4.0285. With the aid of Bleakney's results it was possible to show that the line of mass 4.0285 must be due to triatomic hydrogen $(H_2^1H^2)^+$ containing two light hydrogen atoms and one heavy hydrogen H^2 atom. The mass of the H^2 atom is then equal to 4.02852 minus the mass of a diatomic H_2^1 ion. The mass of H^2 determined in this way was 2.01351 ± 0.00006. If the H^2 nucleus is composed of two protons and one electron the energy of binding is 1.9 million electron volts corresponding to a loss in mass of 0.002 units, much less than the 27 million electron-volts binding energy of helium nuclei.

Other atomic masses that have been measured at the Bartol include two of the isotopes of neon, the chlorine isotopes, the heaviest isotope of boron B^{11}, and the heaviest isotope of beryllium Be^9.

Figure 12 is a spectrum of Be^9 and associated lines of known masses, which was used in the determination of the mass of Be^9. Two spectra are on the plate, one includes the lines Be^9 and carbon C^{12}. The other includes C^{12} and CH_4. The ratio of the masses C/CH_4 is known from Aston's measurements. By measurement of the separations and positions of the $Be - C$ and $C - CH_4$ doublets the ratio of the masses Be^9/C^{12} can be determined as a function of the known ratio C/CH_4. If the masses were exactly 9, 12 and 16 for Be^9, C^{12} and CH_4, the separation of the $C - CH_4$ doublet on the right would be exactly four-thirds of the separation of the $Be - C$ doublet on the left. In Fig. 12, however, the separation of the doublet on the right is not equal to four-thirds of the separation of the other doublet and from a measurement of

FIG. 12.



Mass-spectra used for the determination of the mass of Be^9.

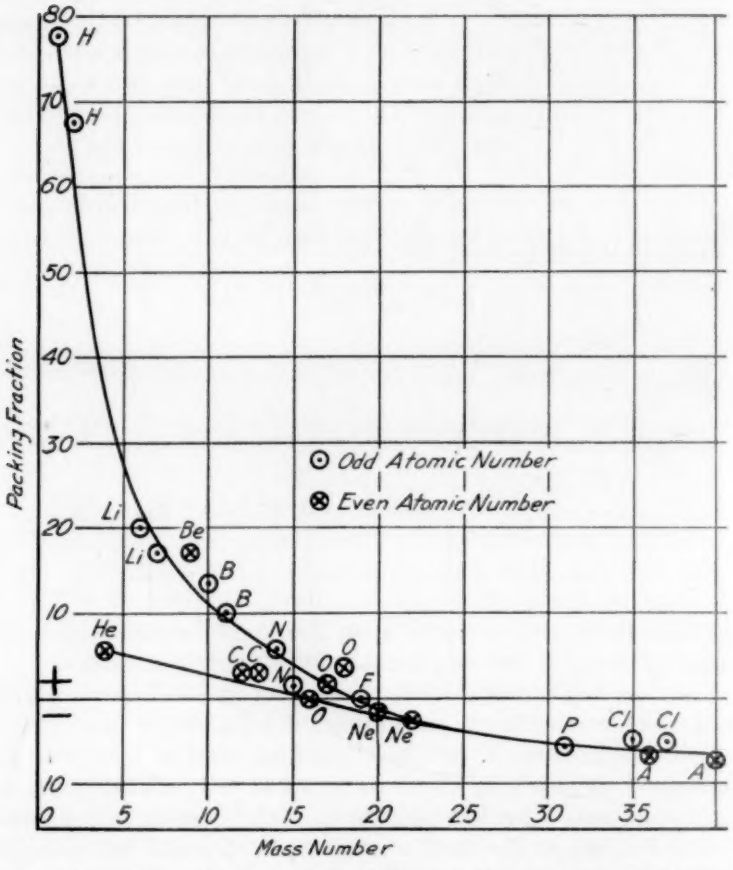
the actual separations and from the known masses of C and CH_4 the mass of Be^9 was measured as 9.0155 ± 0.0006.

As has been mentioned, when protons and electrons are packed together closely in atomic nuclei a loss in mass results which is spoken of as the "packing effect." Aston has expressed the packing effect in terms of a "packing fraction" for atoms which he has defined as "the gain or loss in mass per proton when the nuclear packing is changed from oxygen to that of the atom in question."

In Fig. 13 which includes atomic mass data from a variety of sources including the results of mass-spectrograph experiments, band spectrum analysis, and disintegration experiments, the packing fractions for the lighter atomic species are plotted against the mass numbers of the specific isotopes.

The mass number is equal to the number of protons in the nucleus. The packing fraction of an atom is equal to the measured mass of the atom minus the mass number, divided by the mass number. In the case of beryllium Be^9 the packing

FIG. 13.



The packing-fractions of the lighter atoms plotted against the mass numbers of the atoms (after Aston).

fraction is equal to $\frac{9.0155 - 9}{9} = +17.2$ packing fraction units which are expressed in parts in 10,000. The curves on the plot are merely to show the general trend of the packing

fractions for the elements of odd atomic number, and the other curve shows the trend for the even atomic number, even mass number elements.

The isotopes bordering on the upper curve have been more amenable to artificial disintegration by various agents while the elements on the lower curve give evidence of greater stability in accord with the idea that the smaller the packing fraction the more mass has been lost in the formation of the element and the stronger the energy of binding of the nuclear components. We cannot tell how "stable" the nucleus is until we know something of the structure. For example, if the nucleus of H^2 is composed of two protons and one electron the difference between the sum of the masses of these components and the actual mass of the H^2 nucleus is 0.002 mass units equivalent to 1.9 million electron-volts energy. The H^2 nucleus might very well consist of one proton and one neutron. In this case the mass difference between the components and the H^2 nucleus is only 0.001 mass units so that the neutron and proton may be considered held together less tightly by half than for the structure two protons and one electron. This follows from the fact that in the formation of the neutron itself, if the assumption is made that the neutron is a close combination of a proton and an electron, .001 mass units have been dissipated.

The terms electron and proton must be used advisedly when speaking of the structure of atomic nuclei. It is essential to remember that the first and most important result of Aston's analysis of the isotopic constitution of elements was a simplification of the theory of matter based on the assumption that as electrons and protons appeared to be the units of electricity and matter was electrical in nature, one could say that the nucleus of an atom of mass 20 and net nuclear charge 10 contained twenty protons and ten electrons. This does not mean that the nuclei of atoms actually contain electrons and protons as we know them in the free state. From experimental and theoretical considerations it appears that the electrons lose their identity in nuclei and that what we once knew as an electron has vanished for all intents and purposes except that it appears to have neutralized one positive charge. Even the fast electrons shot out of dis-

integrating radioactive nuclei do not offer unambiguous support to the idea that electrons exist in nuclei with any of the properties they have in the free state. These electrons have been suggested as partners with protons combined into neutrons in a theory proposed by Gamov.

What then may we reasonably assume are the actual building blocks of nuclei? The answer must be sought in data on the radioactive elements and in the results of disintegration experiments on atomic nuclei. Here too the greatest caution must be observed in order not to confuse the smoke outside the gun with the powder in the barrel before the shot was fired. In the radioactive disintegration of atoms there are cases where bullets appear to be bullets, and α-particles or helium nuclei, for instance, may well be α-particles inside and outside the nucleus.

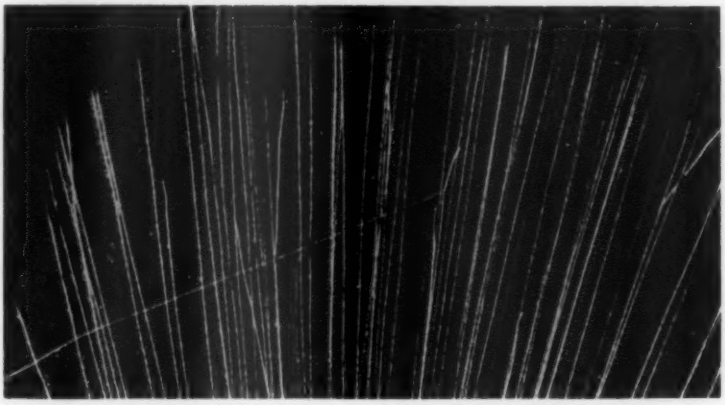
In some structural systems of atomic nuclei the assumption is made that nuclei contain the maximum permissible number of α-particles as fundamental structural units. The measurement of the mass of Be^9 gave the first clear evidence against the general applicability of this hypothesis. The Be^9 nucleus on the "maximum α-particle hypothesis" could contain two α-particles, and the addition of a proton and an electron or of a neutron would result in a nucleus of atomic number 4 and mass of nine units approximately. When the 4 external electrons in the neutral atom are taken into account the maximum mass of the aggregation is 9.01210, and any energy of binding would reduce this figure. The fact that the actual measured mass of Be^9, 9.0155, is appreciably greater renders the proposed structure somewhat fantastic. The structure of the Be^9 nucleus is very probably more complex than has been generally supposed.

Other bullets than α-particles which appear to maintain some of their properties inside of nuclei are protons and neutrons.

Figure 14 is a reproduction of one of Dr. P. M.C. Blackett's Wilson-chamber photographs of the disintegration of a nitrogen nucleus by the capture of a swiftly moving α-particle resulting in the formation of an isotope of oxygen O^{17} and the release of a proton. In a Wilson cloud-chamber the passage of swift charged corpuscles through a gas results in the ex-

pulsion of electrons from the atoms of the surrounding gas, and the ions formed in this way act as condensation centers for the formation of water droplets in an atmosphere supersaturated with water vapor. The long faint thread of droplets is the track of the proton released in the induced disintegration of N^{14}. The short heavy track is the trail of the recoil O^{17} nucleus and the other associated track is the path of the incident α-particle. Pictures of this sort by themselves are not proof of the existence of protons and α-particles in nuclei even though a proton has been ejected and an α-particle has been swallowed up in a nuclear cataclysmic process.

FIG. 14.



Wilson-chamber photograph of the capture of an α-particle by a nitrogen nucleus and the resulting disintegration into a proton and an O^{17} nucleus (Blackett).

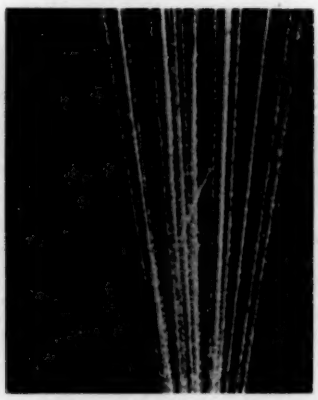
Taken in conjunction with considerations of other results of disintegration experiments they do support the idea that protons and α-particles may occur in atomic nuclei.

Figure 15 is that of another nitrogen disintegration photographed by Blackett which Perrin has suggested can best be explained if the products of the disintegration are an H^2 nucleus and an O^{16} nucleus.

Figure 16 is a reproduction of a photograph of another type of nitrogen disintegration taken by Professor W. D. Harkins. In this case only two tracks are apparent. The disintegrating projectile was a neutron of about two million

electron-volts energy which when captured by a nitrogen nucleus gave B^{11} and an α-particle as the products of disintegration. The neutron, lacking an electrical charge, does not have the power to ionize and so leaves no trail in traversing the Wilson cloud-chamber. The reaction represented by this disintegration of N^{14} + neutron $\rightarrow$ B^{11} + α is reversible, as the bombardment of B^{11} nuclei by α-particles results in the emission of neutrons and presumably nitrogen nuclei too. The disintegration of nitrogen by neutrons was first demonstrated by Dr. N. Feather.

FIG. 15.



Wilson-chamber photograph of the capture of an α-particle by a nitrogen nucleus and the resulting disintegration into an H^1 nucleus and an O^{14} nucleus (Blackett).

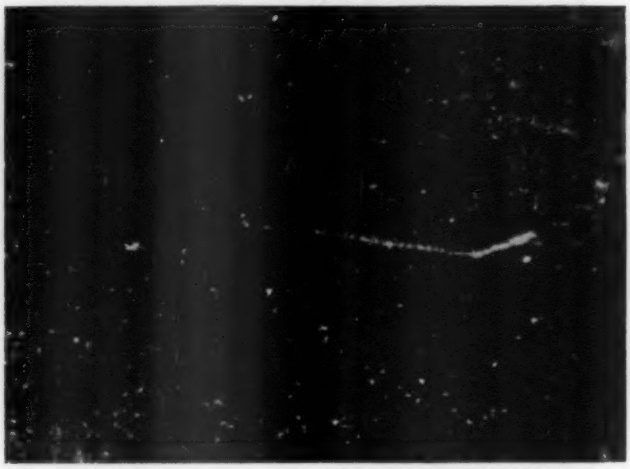
We have then, as possible components of nuclei, electrons, protons, H^2 nuclei, α-particles or helium nuclei, and neutrons. Another possible component is the positron or positive electron, which is believed to have the same mass and magnitude of charge as the negative electron, within the rather wide limits of error necessitated by the difficulties of measurement. The existence of the positron was demonstrated only very recently by Dr. Carl Anderson and has been confirmed by Dr. Blackett. Theoretically the masses should be the same for positrons and electrons and the charges equal but of opposite sign.

Figure 17 is a cloud chamber picture of the path of a

positron photographed by Anderson. So far positrons have only been found associated with cosmic rays or the secondary effects of cosmic rays.

Figure 18 is a schematic arrangement of the atomic species and isotopes of the lighter elements. Harkins has pointed out a great many important statistical relationships among atomic nuclei. This particular method of representation of the nuclear species was introduced by Dr. H. A. Barton and has been influential in stimulating considerations of regularities existing among atomic nuclei and helped start the search

FIG. 16.



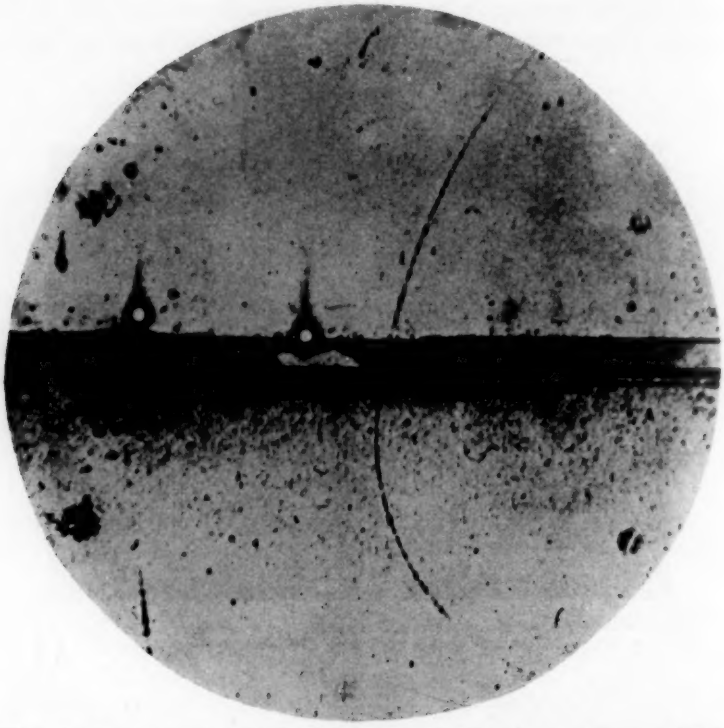
Wilson-chamber photograph of the capture of a neutron by a nitrogen nucleus and the resulting disintegration into an α-particle and a B^{11} nucleus (Harkins).

for H^2. The number of electrons in the nuclei are plotted as ordinates, the number of protons as abscissæ. The words proton and electron are used in the same sense as we have used them in speaking of Aston's simplification of the constitution of matter. Lines have been drawn connecting the various atomic species to emphasize the regularities which appear to be limited to two series over the region depicted.

The result of the addition to a nucleus of various suggested nuclear building blocks is indicated by the lines on the right of the graph. The nuclei H^3 and He^5 are omitted from the plot

because absolutely no direct evidence has been advanced for their existence. The measurements of Bleakney and Kallman give no indication of the existence of He^5 even to one part in 50,000 of He^4. Urey has not been able to detect any H^3 even though his method of measurement was sensitive to one part of H^2 in 30,000 parts of H^1.

FIG. 17.

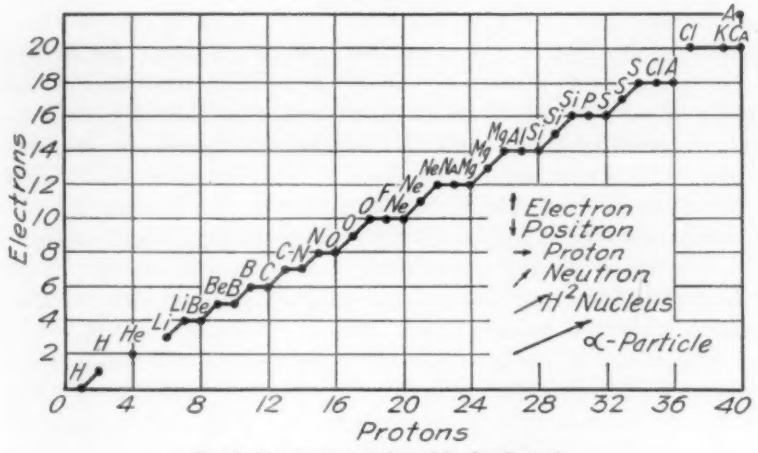


Wilson-chamber photograph of the path of a positron, or positive electron, in a magnetic field (Anderson).

Starting with lithium Li^6 one could proceed through all the atomic species by the addition of a neutron, then a proton, then a neutron and so forth until O^{16} is reached. A new order commences at this point, neutron, neutron, proton, proton, neutron, neutron and so forth. Or one might choose several nuclei O^{16}, O^{17} and O^{18} for example, and proceed by α-

particle jumps to Ne^{20}, Ne^{21}, Ne^{22} and then Mg^{24}, Mg^{25}, Mg^{26} etc. under the assumption that O^{16}, O^{17} and O^{18} are basic nuclear structures favorable to the addition of α-particles. It is not profitable for the present to pursue these atom building exercises further. All efforts are being made to remove such hypothetical atom building from the realm of pure speculation by judicious use of available data and the ingenious devising of new methods of attack on atomic nuclei. The complexity of the problem is enhanced when heavier nuclei are considered. More data on the disintegration of atomic nuclei, the knowledge of their masses to an accuracy of one part in a hundred

FIG. 18.



Regularities among atomic nuclei (after Barton).

thousand or better, and the further study of nuclear moments and hyperfine structure of spectral lines of the rarer isotopes (made possible by the separation of isotopes in quantity) may reasonably be expected to give concrete advances towards the solution of the baffling problem of the structure of atomic nuclei.

In conjunction with the results from disintegration experiments, the accurate measurement of atomic masses has been valuable for the study of atomic energy. I have already mentioned, in the discussion of the packing effect, the equivalence of mass and energy theoretically deduced by Einstein.

An experimental proof of that relation rests in the detailed consideration of mass and energy relationships in artificial disintegration processes. The most striking case is provided by the experiments of Dr. J. D. Cockcroft and Dr. E. T. S. Walton on the disintegration of Li^7 by proton bombardment. The synthesis and disintegration may be represented symbolically as Li^7 + proton $\rightarrow$ 2 α. On the left hand side of the reaction the masses of the components are 7.012 + 1.00724 = 8.019, where the mass of Li^7 has been taken from the measurements of Dr. J. Costa. On the right of the equation the mass of the two α-particles plus 3 electrons is 8.0038 (the mass of the electrons must be added to take account of the three external electrons of Li^7 which, however, do not enter into the reaction proper). There is an excess of mass of 0.0152 mass units on the left of the equation. The total energy of the α-particles was measured as 17.2 million electron volts (probable error not given by Cockcroft and Walton) equivalent to 0.0184 mass unit if Einstein's theory is correct. 0.0157 $\pm$ 0.003 mass unit are available for conversion into kinetic energy of the α-particles when the energy of the incident proton is included with the previous figure 0.0152. Within the error the equivalence of mass and energy is an established fact and the transformation of mass into kinetic energy is demonstrated.

The mass of the neutron is of great fundamental importance. Assuming the equivalence of mass and energy the mass of the neutron can be deduced from disintegration experiments. Neutrons make their appearance as one of the products of disintegration of B^{11}, Be^9, and Li^7 when these nuclei are bombarded by α-particles.

From Aston's mass data and Chadwick's disintegration experiments, the mass of the neutron is 1.0067 $\pm$ 0.001 from the reaction $B^{11} + \alpha \rightarrow N^{14}$ + neutron. The disintegration of Li^7 has been investigated less fully than the boron reaction. One can, however, use the data of Dr. I. Curie-Joliot, Dr. F. Joliot and Dr. P. Savel to set an upper limit 1.0063 $\pm$ 0.0008 for the mass of the neutron which appears as a product of the reaction $Li^7 + \alpha \rightarrow B^{10}$ + neutron. A lower limit for the mass of the neutron is 1.0057 $\pm$ 0.0002 calculated on the assumption that the nucleus of H^2 is composed of one proton and one neutron.

It has been suggested by Anderson that the proton is not an ultimate unit of matter but is a close combination of a neutron and a positron, the fundamental units being electrons, positrons and neutrons. The mass of a proton from mass-spectrograph results is 1.00723. The mass of a neutron and a positron (under the assumption that the positron and electron have equal masses) is 1.0067 + 0.00055 = 1.00725 units. At best only a small amount of mass is available for packing and the apparent stability of protons is against the idea that neutrons are the primary particles and that protons are of a secondary complex nature.

The mass of the neutron 1.0067 is in better accord with the idea that protons and electrons are fundamental units and that the neutron is a close combination of a proton and an electron. In this case the binding would amount to about one million electron-volts.

The disintegration of Li^7 by α-particle capture when studied in detail suggests an interesting possibility. The sum of the masses of $Li^7 + \alpha + 2e$ is 11.01416. The sum of the masses of the products B^{10} + neutron is 11.0202 if we assume that the neutron is the same as the neutron emitted in the disintegration of B^{11}. The difference in mass between the two sides of the reaction is almost exactly equal to the maximum energy of the incident α-particle expressed in mass units. Can this be a case in which the energy of motion of the α-particle is transformed into mass, a creation of matter from energy?

Several possible explanations suggest themselves. First, the experimental evidence may be wrong and this process of synthesis and disintegration does not actually occur. Second, the mass of the neutron emitted in this process is less than we have assumed. Finally, it may be that the α-particle is captured and remains in a high energy level in the B^{10} nucleus, that is the α-particle with its full kinetic energy has been fenced in by the potential walls of the B^{10} nucleus.

The first alternative explanation must be discarded as the experimental evidence appears unassailable that neutrons are a product of the disintegration of lithium. The second alternative explanation need not be considered as the measured energy of the neutrons is in agreement with the idea that

the neutrons from the disintegration of lithium have the same mass as the neutrons from the B^{11} disintegration. The third suggestion might be seriously considered if only one or two million electron-volts energy were involved as the magnitude of an α-particle level. But five or six million electron-volts cannot be so easily accounted for as an energy level within the stable B^{10} nucleus.

The remaining possibility seems therefore the most likely, namely that we have here a true case in which the energy of motion of the α-particle is transformed into mass, or in other words a creation of matter from energy.

The annihilation of mass to give energy was suggested by Jeans as early as 1904, and the theoretical relationships were later worked out by Einstein. Disintegration experiments and the results of measurements of atomic masses have allowed quantitative examination of the theories. Such measurements, in the hands of Aston and Costa have helped to confirm theories and to replace speculation by facts. There is every reason to believe that further researches on isotopes will continue to aid in the understanding of some of the fascinating problems of nuclear physics.

ON ELECTRON OPTICS.*

BY

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ABSTRACT.

For many experiments in physics and in some engineering applications, it is necessary to produce electron bundles, or as they are often called, "electron beams" of considerable intensities. Various methods have been used for directing a cloud of electrons evaporated from an emitting surface into a beam and then concentrating this beam to a desired degree. The concentration of electron beams in high vacuum depends entirely upon fields of force, either electric or magnetic, while in low vacuum or in rarified rare gas it depends also upon the action of the field of ionized gas molecules.

In high vacuum the fields of force act upon the electron beam in a manner similar to the action of lenses upon a beam of light. An improperly shaped field produces effects similar to spherical aberration in poorly corrected lenses; non-uniform velocity of electrons in the beam results in effects similar to chromatic aberration of light.

This optical analogy is not perfect. In the case of the electron beam the velocity varies continuously throughout most of the path and indices of refraction employed usually are greater than in the optical case. Moreover, space charge in beams of high intensity limits the concentration attainable; consequently, even theoretically, an electron beam can never be brought up to a mathematical point as in the case of light optics. Many secondary effects are present which complicate the problem still further.

In focusing electron beams, both electrostatic and electromagnetic methods have been used extensively. The electrostatic method, however, seems to be preferable, especially when the beam is to be deflected. Precautions should be taken not to destroy the focusing of the beam during deflection.

INTRODUCTION.

An electron beam may be defined as a well concentrated electron bundle in which all the electrons are moving with approximately the same speed and direction, and in this way, different from the well-known diffused emission of electrons in a thermionic tube.

The electron beam has been familiar to physicists for a long time, having been introduced in a form resembling that

* Presented before the Optical Society of America, Feb. 24, 1933.

of present days by Braun many years ago. However, only during the past few years has it attracted general attention due to the many possible applications. Since that time a great deal of research has been carried on with this problem, and particularly with methods of concentrating the beam into a sharp bundle.

The concentration of the electron beam can be accomplished by several methods. Some of them, which are used for concentration of electrons in low vacuum, or in the medium of rarefied rare gases, and where the focusing depends wholly, or partly, upon the action of the field of ionized gas molecules, will not be discussed in this paper. The electron beam in high vacuum, on the other hand, can be concentrated entirely by the action of fields of force, either magnetic or electrostatic, and both these methods will be discussed in this paper.

ELECTROMAGNETIC FOCUSING.

A classical method of concentration of the electron beam is by means of a coil coaxial with the beam. The direct current flowing through this coil creates a magnetic field parallel to the beam which converges the electrons into a small bundle. The theory of the concentration coils is simple if the coil is very long, so that the magnetic field can be considered as homogeneous throughout the length of the beam, and if there is no electrostatic field. An electron in the bundle in motion along a line of force in the magnetic field will not be affected by the field and will continue to move in the same direction. But the motion of an electron moving at an angle α with the magnetic field H can be considered as composed of two components, one along the field ($V \cos \alpha$) and the other at right angles to it ($V \sin \alpha$). This latter component will be influenced by the field just as though the first component were not present. As a result of this influence, the projection of the path of the electron upon a plane perpendicular to the axis is bent into a circle by the field, so that the paths of electrons are helical [1] (Fig. 1).

The time, t, which is necessary for the electron to make a complete turn of the helix can be figured from the general equation of force upon an electron moving in a uniform mag-

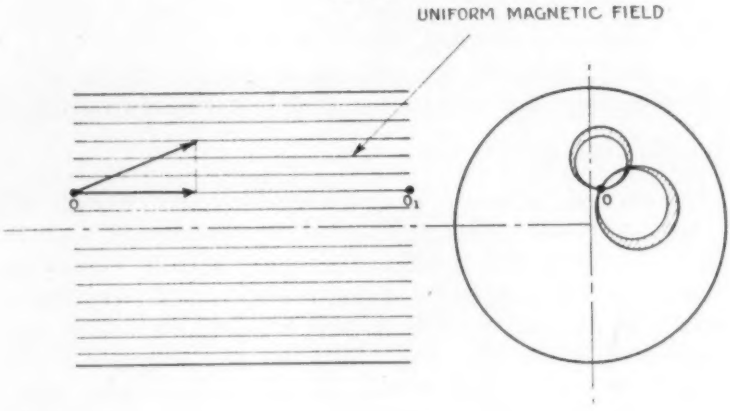
[1] H. Bush, *Archiv. für Electrotechnik*, XVIII, 1927, p. 583.

netic field.

$$\frac{mv^2}{r} = Hev, \tag{1}$$

where m = mass of the electron,
v = the radial velocity, = radial velocity = $V \sin \alpha$,
r = a radius of the circle,
H = the magnitude of magnetic field,
e = the charge of the electron.

FIG. 1.



From this equation we can write

$$r = \frac{mv^2}{Hev} = \frac{v}{\frac{e}{m}H}. \tag{2}$$

We can express the time, t, necessary to complete one circle or turn of the helix as

$$t = \frac{2\pi r}{v} \tag{3}$$

Substituting (2) into (3) we get

$$t = \frac{2\pi}{\frac{e}{m}H}.$$

From examination of this value of t, we shall see that it does not depend upon the angle α by which the electron departs from a line of force in the magnetic field. This result means that all the electrons starting from the same point source arrive by the helical path simultaneously and with equal longitudinal velocity at the same point, at distance l from the point source. Consequently, if the electrons start to move from a certain finite area o, they all will reproduce this area at a distance l at the interval of time, t. This new area o_1 will be the exact image of o standing upright and in its natural size. Since l is inversely proportional to H, a certain field strength is needed to focus at a given distance. If the distance is doubled, the field may be reduced to one-half. The focusing in the uniform magnetic field, in fact, is so theoretically clear and precise that it was used by Bush for determination of $\frac{e}{m}$.[2]

In practice, however, one seldom uses the uniform field but uses coils whose length is small in comparison with the length of the beam; besides, the beam usually passes also through a strong non-uniform electrostatic field. The mathematical treatment of such a problem became much more complicated than the one with the uniform field. The problem, however, was solved by H. Bush[3] who proved mathematically that even with a non-uniform magnetic field, and with the existence of non-uniform electrostatic field, the focusing exists if certain conditions are fulfilled. These conditions require that fields and space distribution of charge must have axial symmetry, the bundle of rays must be sufficiently narrow with its axis coinciding with the axis of symmetry and finally the initial velocity must be the same for all the electrons.

With these conditions fulfilled, Bush proved that the short focusing coil acts upon an electron beam like a lens on a beam of light. The analogy is particularly striking for the hypothetical case where the length of the coil approaches zero. In this case the image of the source of electrons is inverted 180° and the size is enlarged or diminished according to the

[2] H. Bush, *Physik. Zeit.*, Bd. 23, **5**, 438, 1922.
[3] *Ann. der Phys.*, **81**, p. 974, 1926.

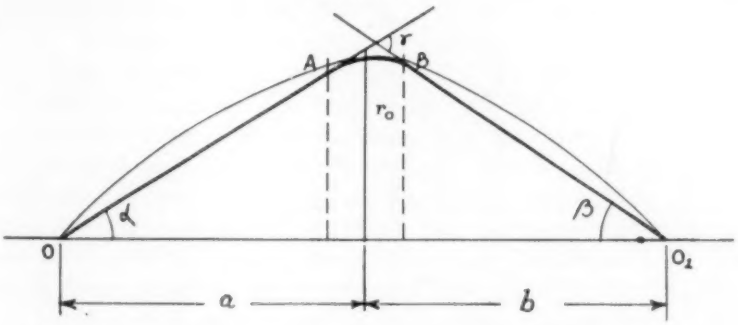
position of the coil in complete analogy with the well-known optical formula for the relation between the focal distances

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f}. \tag{4}$$

Since in practice the length of the coil does not ever reach zero, the image of the source is always turned at an angle smaller than 180°, decreasing with the increase of the length of the coil, and reaching the limiting case when the coil becomes as long as the magnetic field can be considered as uniform. The angle of rotation then becomes zero, or as was mentioned before, the image in the uniform field becomes upright.

The case of focusing with a short coil can be represented as shown in Fig. 2, in which the action of the magnetic field is

FIG. 2.

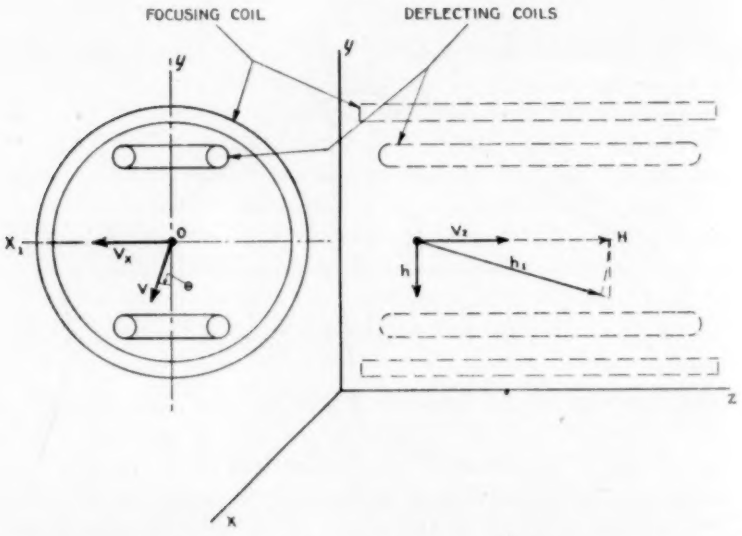


confined to the region between A and B. An electron emitted from the source o at an angle α to the axis of the field follows first a straight line until it enters the field at A; then it turns until it leaves the field at B and proceeds again on a straight line with the angle β to the axis. This condition represents the case when an electrostatic field is not present. When the electrostatic field is also present, which is usually the case, the electrons travel along a continuously curved line instead of a straight line, but the analogy with the optics in respect to focusing of the image still exists. It corresponds to a hypothetical case in optics in which the index of refraction is not constant, but varies throughout the path of the beam.

The analogy with optics is still more striking as the magnetic focusing exhibits an effect analogous to the "spherical aberration." The electrons are focused the more sharply, the smaller is the angle α; also, the image is more diffuse the larger the cross-section of the beam as it passes through the coil.

This theoretical consideration was verified; the results are in very good agreement with the theory. Since the beam consists of electrons, it can be easily displaced by a magnetic or electrostatic field applied at right angles to the axis. If a magnetically focused beam is to be deflected by the magnetic field, there occurs an additional complication, as a result of interaction of the two magnetic fields. This can be explained by the diagram of Fig. 3.

FIG. 3.



Suppose the beam is moving at a velocity v_z along the axis, Z, coaxial with the focusing field H. A deflecting field h is applied at right angles to the beam in order to displace it in the direction X. This motion of the electrons in the direction X in the presence of the focusing field H results in a deflection which is not at right angles to the deflecting field

h, but at some other angle θ which is a function of the intensity of H. If, therefore, we obtain an image of the source of electrons by means of a focusing coil and then displace it by another magnetic field within the field of the coil, we will have two additional rotations which complicate the predicted results; one the rotation of the image around the axis of the symmetry and the second a rotation of the displacement.

The image of the beam will suffer also another distortion in case of displacement by a magnetic field due to the non-uniformity of this field which is always present on account of the finite size of the deflecting coils. This distortion is produced by the fact that different points of the cross-section of the beam are traversing the magnetic field of different intensity and therefore are deflected at various degrees. This, of course, displaces the mutual position of points of the image and distorts it.

ELECTROSTATIC FOCUSING.

As it was mentioned before, the magnetic focusing is practically always complicated by the presence of a strong electrostatic field. This field is often used to increase the energy of the beam which, in turn, is a very important point in practical application of the beam The idea of using the electrostatic field for both acceleration and focusing of the electron beam is very attractive and consequently a great deal of effort has been concentrated in this direction. A paper describing the application of this principle for cathode-ray oscillograph was read by the writer at the November meeting of the I. R. E. in 1929.

Hamiltonian classical mechanics shows an analogy between the behavior of small particles in motion and the action of light rays. A particular case of this general analogy is the motion of charged particles in a homogeneous electric field. An electron beam entering a field layer, i.e., two surfaces near each other at different potentials, obeys the same laws as a beam of light incident on a surface separating two opposite media with different indices of refraction. This analogy was verified experimentally by M. Knoll and E. Ruska,[4] who

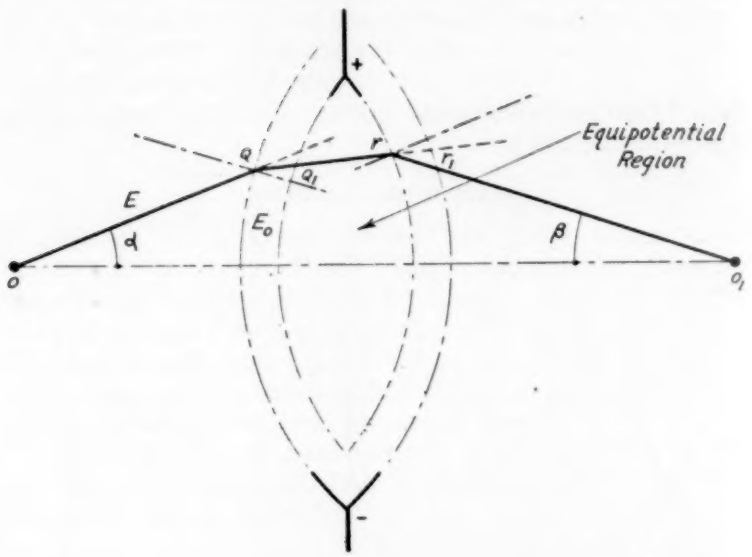
[4] *Ann. der Physik*, Band 12, February, 1932. (Also *Zeit. für Physik*, 78, 5–6, 318–339.)

constructed the models of electronic lenses. The glass of the optical lens was replaced by electric field by means of fine mesh screen, as shown on Fig. 4.

The index of refraction of the layer of electric field between two screens can be represented in terms of two voltages E of the beam, and E_0 of the double plane voltage

$$n = \sqrt{1 + \frac{E_0}{E}} + \text{term of higher order which can be neglected.} \qquad (5)$$

FIG. 4.

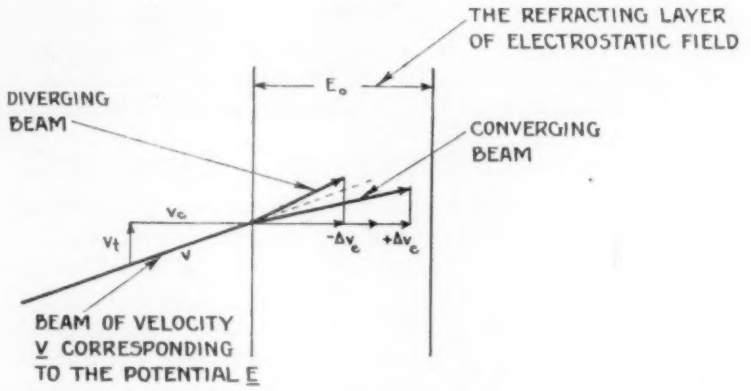


Since E_0 can be of any value with respect to E, the index of refraction can vary within much wider limits than in optics. It is evident that when E_0 is accelerating, we will have $n > 1$ and therefore the lens acts as a converging one; with E_0 negative, $n < 1$ and the same lens will act as a diverging one. The refraction of electrical lenses can be seen clearly from the vector diagram, Fig. 5. The velocity of the beam entering the layer of the field E_0 can be represented by two vectors, V_e normal to the plane of the field, and V_t tangential to it. If $E_0 > E$, the field is accelerating and therefore V_e

increases, V_t remains the same, and the emerging beam is bent toward the normal or converges. If $E_0 < E$ then V_e decreases and the emerging beam is bent from the normal or diverges.

The magnitude of the index of refraction is usually much higher than we have in optics. While, for instance, for glass we have $n \sim 1.5$, for electric lenses with $\frac{E_0}{E} = 100$, $n = 10$. The analogy with optics immediately opens great possibilities of creating all kinds of electrical lenses, mirrors, prisms, etc. The electrical method allowing practically an unlimited number of values for n and its reversibility by reversing the

FIG. 5.



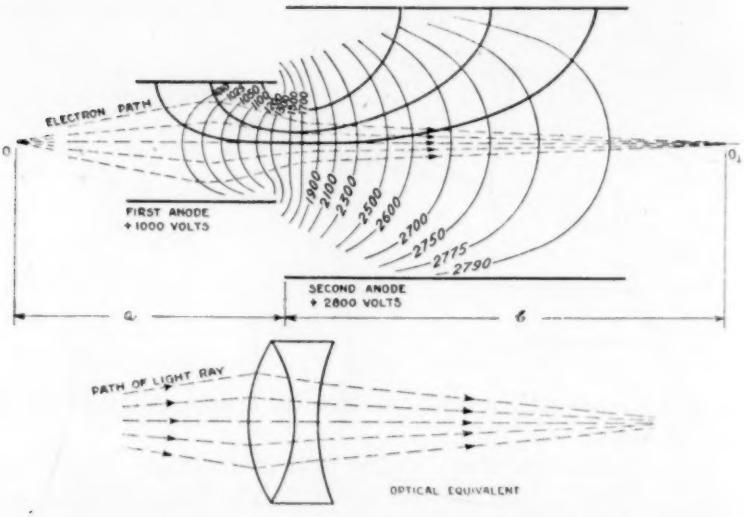
potentials is actually much more flexible than in corresponding cases in optics.

Two deviations from strict optical analogy should be borne in mind. The first one is due to the finite thickness of the field layer, as distinguished from corresponding (reflecting or refracting) planes in optics. The emerging position of the electron is displaced tangentially (from Q to Q_1 in Fig. 4) with respect to the incident position. This displacement, however, can be kept within reasonable limits by keeping the thickness of the layer small. In the case of a symmetrical lens arrangement, as shown on Fig. 4, there are two layers, one accelerating and another retarding and, therefore, opposing each other.

The second deviation is due to the fact that wire mesh electrode is not a continuous surface. The electric field converges upon the wires of the mesh so that it is not uniform over the surface of the screen; the deflection of electrons passing close to the wires is greater than the deviation of electrons which enter in the middle of the mesh. While the first fault has no analogy in light optics, the second fault due to the mesh can be compared with the properties of an incompletely polished lens surface.

There is, however, another way to produce a focusing electrostatic field without using wire mesh electrodes, but by means of concentric cylinders or coaxial diaphragms. A typical example of the first one is shown on Fig. 6. From the

FIG. 6.



equipotential lines, one can see that in this case there is a single accelerating field in which the curvature varies, while in the case of the wire mesh lens of Fig. 4, there were two regions in which the curvature of the field was approximately constant. It can be seen from the lines of force that the left part of the field in this case is converging, while the right one is diverging. The optical equivalent in this case, therefore, is that of a lens composed of positive and negative parts, as

shown on the same figure. The resulting effect is the difference between the action of these two lenses. That the difference is not zero in this case is due to two reasons. First, from configuration of the electrodes, the magnitude of the diverging field is less than that of the converging. Second, the velocity of the electron is increasing continuously and is, therefore, higher when it passes the diverging part of the field. Since the bending of the electron path by the field is inversely proportional to its velocity, the action of the right part of the field is smaller. The total action of combined fields in this case is the converging of the beam toward the axis.

If the source of electrons is a point, it will be reproduced in space at o_1 on the other side of the electrical lens. If the source of electrons is a finite area, such as surface of a hot cathode, it will be reproduced, as by its optical equivalent, as an inverted image at a plane through o_1. The size of the image will be enlarged or reduced according to the ratio $\frac{b}{a}$ of focal distances. These distances, of course, are functions of the applied potentials and configuration of electrodes.

A number of such electrical lenses can be used on the path of the beam in various combinations. An example of a combination of two diaphragms equivalent to one positive and one negative lens is shown on Fig. 7.

As in the case of magnetic focusing, the optical analogy is imperfect. As previously mentioned, variations in electron velocity and in field shape produce the effect of continuously variable index of refraction. The expression for n, of course, becomes much more complicated than given for the case of the lenses made with wire mesh. The effect of variable n has a similarity to the well-known phenomenon of "mirage," or still closer to the reflection of radio waves from the Heaviside layer.

The second important departure from optical analogy is, that the space charge created by electrons themselves affects their path; that is quite different from the conditions which we have in the case of light.

In general, an electron moving within a beam with velocity V is subjected to two forces: a radial force outward

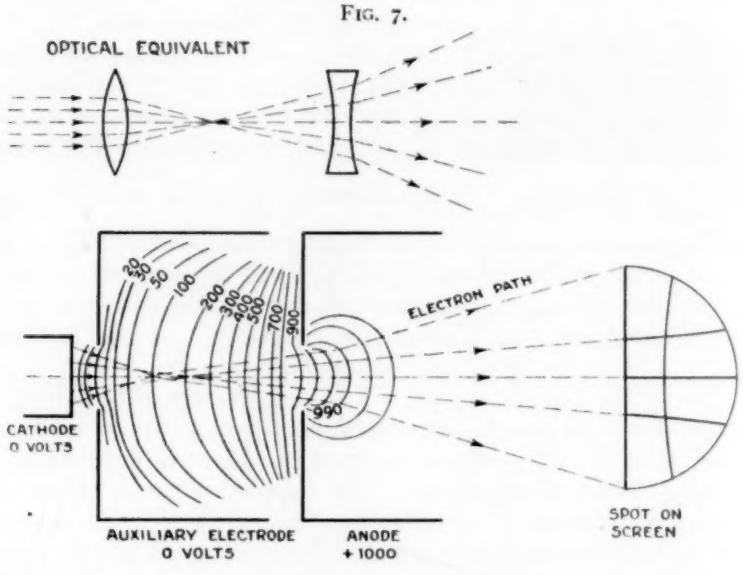
due to an electrostatic field E, and a radial force inward caused by a magnetic field H. Assuming $\frac{n}{v}$ electrons in unit length of the beam of radius r, we have a radial electrostatic field E at the surface of the beam [5]

$$\text{with } i = ne \qquad E = \frac{2ne}{rV} \text{ e.s.u.} \tag{6}$$

and the radial electrostatic force on a single surface electron

$$= \frac{2ne^2}{rV} \cdot C^2 \text{ e.m.u.} \tag{7}$$

FIG. 7.



The electromagnetic field H is

$$= \frac{2i}{r} = \frac{2ne}{r} \text{ e.m.u.} \tag{8}$$

Radial electromagnetic force on a single surface electron

$$= -Hev = -\frac{2ne^2V}{r} \text{ e.m.u.} \tag{9}$$

[5] E. E. Watson, *Phil. Mag.*, April, 1927, p. 849.

Total radial force F on a surface electron as a sum of both forces was described by Watson as

$$F = \frac{2ne^2(C^2 - V^2)}{V} \cdot \frac{1}{r}. \tag{10}$$

It can be seen from this that if the velocity of electrons could reach the velocity of light the electrostatic repulsion will be compensated for by the magnetic attraction due to the motion. In most of the cases where the velocity of the beam is equivalent to 10,000 volts or less, the magnetic attraction is negligible. When, however, as in high voltage oscillographs, the velocity of the beam reaches one-third of the velocity of the light or higher, this term cannot be neglected and the magnetic attraction exercises appreciable influence on the focusing of the beam.

For low velocity beams the electrostatic repulsive forces introduce a limitation for the minimum diameter of cross-section of the beam to which it can be focused for given intensity. This limitation can be estimated assuming an ideal case of a perfect electrostatic focusing system without any distortion and, therefore, capable of concentrating the beam into a mathematical point. The equation of motion of electrons is

$$\frac{d^2r}{dt^2} = E_r\left(\frac{e}{m}\right), \tag{11}$$

where r = radius of the beam,

E_r = value of electrostatic field built up by space charge.

Introducing the value of the electrostatic field given above (6) and integrating, we will obtain the expression for the ratio between the diameters of emerging beam and minimum cross-section of the focused beam

$$\log\frac{D_0}{D_{\min}} = \frac{V_0^2}{2a}, \qquad \text{where } a = \frac{2iC^2}{u_0}\frac{e}{m}, \tag{12}$$

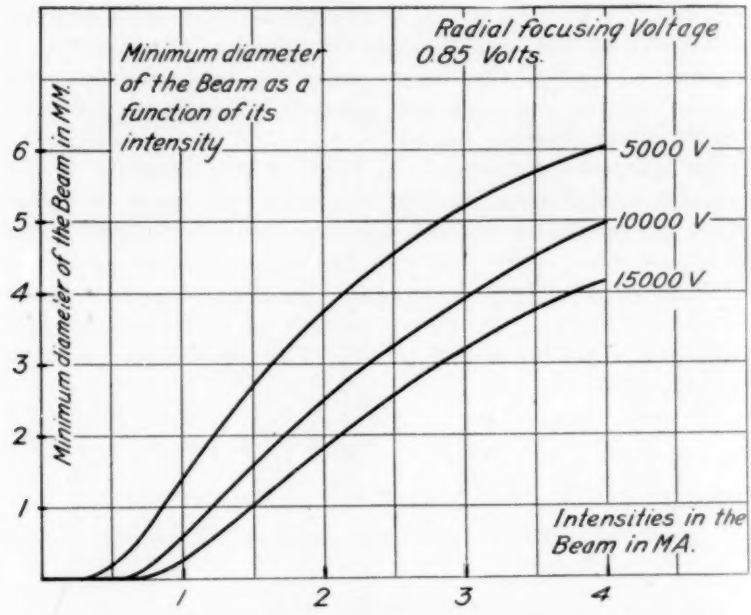
V_0 = radial velocity of electrons in the beam impressed by focusing field,

C = velocity of the light,

u_0 = velocity of the beam.

A family of curves obtained from this equation for various intensities of the beam is given in Fig. 8. These curves give the theoretical minimum of diameters d_1, d_2, d_3 (Fig. 9) for various voltages, which it is possible to obtain at a given intensity due to the space charge effect with a beam of 1 cm. initial diameter and given field. This limitation is particularly noticeable when an electron beam of high intensity is concentrated in the very small space. Such a place may

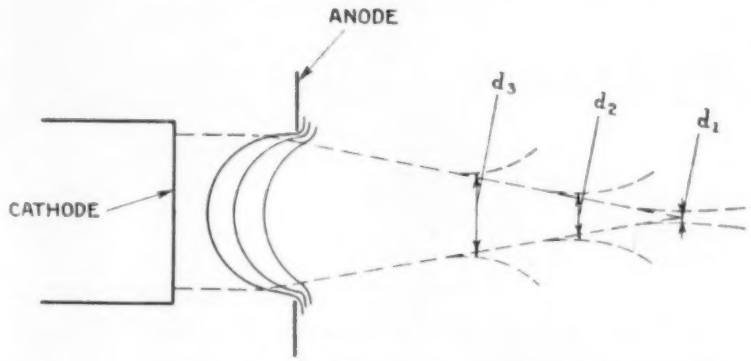
FIG. 8.



occur not only at the end of the beam, but also in the proximity of the cathode as is shown on Fig. 7. The reason for the latter arrangement is that the source of electron emission in high vacuum is almost necessarily thermionic and, therefore, there is quite a definite limitation in current per square unit of area of the cathode. If the cathode beam should be focused in a very small diameter which corresponds to the diameter of the image of the cathode, the cathode quite obviously should be small. To partly overcome these diffi-

culties, it is sometimes advisable to reproduce not the image of the cathode but some intermediate aperture, which can be of much smaller dimension than the cathode. This, however, cannot be carried too far, since here, as in optics, we encounter an effect analogous to spherical aberration. The electrical lenses do not perfectly focus the beam. The outer parts of the beam are usually brought together closer to the cathode and the inner ones farther away from it, as shown on Fig. 10, resulting in spoiling the definition of the spot. As a rule, the greater the initial cross-section of the beam, the stronger is the effect of this aberration. The departure of focusing electrodes from circular symmetry and misalignment of the

FIG. 9.



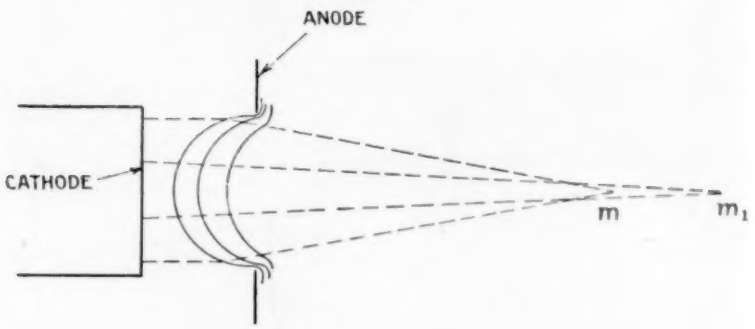
apertures, of course, play a very strong part in this distortion, and imperfection of the spot in most cases is the combined effect of these two factors.

Although the electrons in the beam in high vacuum are usually of quite uniform velocity, there are some which differ from the average. This departure is partly due to the random distribution of velocity of emission from the cathode, and partly due to secondary emission from edges of apertures. The effect of this non-uniformity of velocities is that the slower electrons are focused sooner and the faster ones later than the average, with the result of still more decreasing the definition of the spot. Fortunately, the effect is not very pronounced and in most cases can be disregarded. The

chromatic aberration in light optics, where different colors are refracted differently by the glass lenses, can be compared with this effect.

As a method of decreasing the secondary emission, we often coat edges of apertures with carbon or similar non-emitting materials. When the beam potential is around 10,000 V. or higher, an additional disturbance often arises in the shape of cold emission from sharp edges of apertures and other metal parts. Careful smoothing and even polishing of edges of all metal parts subjected to a high electrostatic field usually prevents this emission.

FIG. 10.



As in the case of magnetic focusing, here again it is often important to construct a tube where the electron beam can be easily deflected. The deflection, of course, can be either magnetic or electrostatic. The point of application is after the focusing lens and great care should be taken not to disturb the focusing field by the deflecting fields. The accomplishing of this requirement is quite a problem by itself and in general should be solved separately for every particular case.

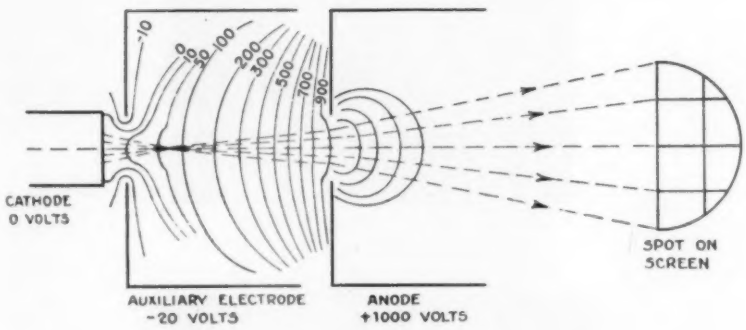
ELECTRON MICROSCOPE.

A very interesting and direct application of electron optics is the case of the so-called "electron microscope" described by E. Bruche and H. Johanson.[6] By means of

[6] *Ann. der Physik*, **5**, November, 1932, p. 129; also E. Bruch, *Zeit. f. Physik*, **78**, 3–4, 179–198, Sept., 1932, and M. Knoll, F. Q. Hontermans and W. Schultze, *Zeit. f. Phys.*, **78**, 5–6, pp. 340–362, October 4, 1932.

this device a magnified image of the cathode surface is obtained on a fluorescent screen, as a result of its own electron emission. The general arrangement of a modified form of electron microscope is shown on Fig. 11. A magnified image of the indirectly heated cathode is focused by means of two electrical lenses on the fluorescent screen. A photograph of this image magnified electrically approximately 50 times is shown on Fig. 12. It shows that the emission is not uniform throughout the surface but consists of a conglomeration of bright spots and patches. If we change the temperature of the cathode, the pattern begins to shift, showing clearly changes in distribution of emitting substances. The effect

FIG. 11.



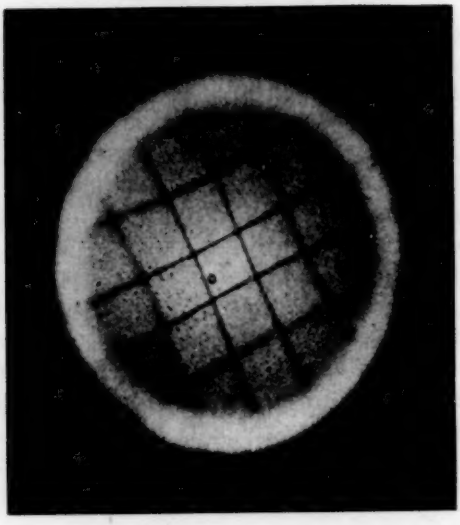
of bombardment of the cathode by gas or vapor molecules, also, can be clearly observed with this device. A still more interesting phenomenon can be observed if we scratch the surface of the cathode by a series of parallel lines. The image of such a surface is shown on Fig. 13. The magnification in this case is about 10 diameters.

Usually the parallel lines from the cathode surface are imaged bent either inward or outward showing the spherical aberration of the electrical lenses. By proper adjustment of potentials, the lines can be straightened out indicating the correction of aberration. This gives a very simple and convincing means of studying the action of focusing fields.

It is not even necessary to construct a special device for observation of the cathode surface, since practically every

FIG. 12.

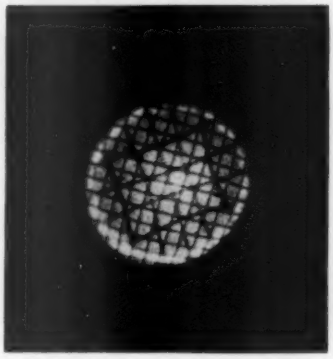
FIG. 13.



high vacuum cathode oscilloscope will serve the purpose. It is usually necessary only to readjust the accelerating potentials and to lower the cathode temperature (to reduce space charge) in order to receive a large image of the cathode surface on the screen. The appearance of this image gives a very good idea of the condition of the emitter and alignment of the apertures.

Not only can the image of the cathode be gotten but it is also possible to bring on the screen the magnified images of the diaphragms, particularly the ones close to the cathode. If identification marks are previously introduced on the edges of these apertures, one can observe and verify for himself the effect of inverting the image by the electric lens.

FIG. 14.



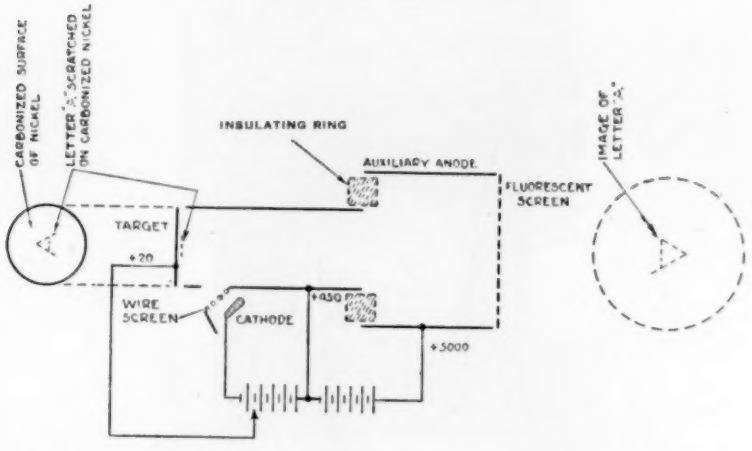
If we insert a wire mesh somewhere in the anode, where it does not interfere with the focusing field, we obtain a sharp shadow of this mesh on the fluorescent screen, as shown on Fig. 14. This indicates that the focusing of the electron beam is already accomplished near the aperture of the anode, and from there the electrons proceed in straight lines. That the mesh does not interfere with the focusing is shown by the appearance of sharply focused lines from scratches on the cathode surface.

Any kind of electron emitting surface can be reproduced upon the fluorescent screen. We have found, for example, that secondary emission from a cold surface bombarded by

electrons is suitable for the purpose. The arrangement of electron microscope adapted for secondary emission is shown in Fig. 15.

The target is subjected to bombardment by the primary electrons from the thermionic cathode. These electrons are accelerated by a positive potential applied to the wire screen which, in turn, is connected to the main body of the device. For the particular arrangement used, the accelerating voltage was 450 volts, while the target was approximately 20 volts positive with respect to the cathode. The secondary electrons are drawn from the surface of the target by the field

FIG. 15.



from the main anode, and focused on the fluorescent screen by the field between the main and auxiliary anodes.

A photograph of the image obtained with this device is shown in Fig. 16. The target in this case was a piece of carbonized nickel which had been scratched so as to remove the carbon, forming a letter *A*. Since the secondary emission is higher from the nickel than from the carbon, the letter appears bright on a dark background. The image of the letter appears quite sharp indicating that a good focus was obtained. This is rather surprising considering the wide variation in velocity and direction of emission one would expect from the secondary electrons.

In another experiment the target was composed of a sheet of mica on which had been deposited a coating of silver. In this case, the image of scratches on the surface of the target was poorly defined, for the electrostatic field due to accumulation of charge on the insulating mica surface altered the initial direction of the secondary electrons. This effect suggests that the electron microscope, with suitable modification, might be used in the study of charges on insulators subjected to electron bombardment.

FIG. 16.

The electron microscope is not the only application of electron optics. We are already familiar with the electronic spectroscopes, in which electrons of various velocities are sorted by magnetic or electric fields. The study of this new technique has just begun and we can expect it to be applied to many new fields.

In conclusion the writer wishes to acknowledge the assistance of Mr. Harley Iams, and other members of the Laboratory who performed some of the experimental work mentioned.

Insect Coloration and the Relative Acceptability of Insects to Birds.—FRANK MORTON JONES (*Trans. of the Entomological Soc. London*, 1932, LXXX, 345–385) has made an exhaustive research on the theory of warning coloration. The experiments, which extended over a period of two years, were made on 5,000 freshly killed insects of 200 species including moths, butterflies, beetles, and other insects. The relative acceptability of these insects to 11 species of wild insectivorous birds was determined in their native habitat. Various factors governed relative acceptability. Larger insects were usually preferred, as were those with duller colors and obscure patterns. The least acceptable insects were often characterized by conspicuous markings of yellow, orange, or red, or were brilliantly metallic; they had a daytime habit of display rather than of concealment. Experiments were also made concerning the acceptability to ants of both insects and mixtures of cream and extracts prepared from the insects by means of amyl acetate, alcohol, chloroform, and water. No general agreement developed between the two series of experiments, those with birds and those with ants. However, insects which feed on plants with an abundant, acrid, and poisonous latex such as the milk weeds (*Asclepiadaceae*) and the *Apocynaceae* during both larval and adult life were not acceptable to either birds or ants. The great prevalence of the types of coloration commonly interpreted as "warning coloration" among the insects feeding upon these plants, and the behavior of both the ants and the birds toward the insects having these food-plants, support the belief that in these insects warning colors and plant-derived deterrents or poisons combine to render them relatively unacceptable to birds. Other factors must govern the relative unacceptability of many insects to birds. The paper is illustrated with 11 full-page plates, one of which depicts the insects in their natural colors.

J. S. H.

Fluoride Content of Sea Water.—THOMAS G. THOMPSON AND HOWARD JEAN TAYLOR (*Ind. and Eng. Chem.*, Analytical Edition, 1933, V, 87–89) find that the fluoride content of sea water is a function of the dissolved salts, and ranges between 1.0 and 1.4 milligrams of fluoride anion per liter. It does not exhibit seasonal variations, and increases with the depth until approximately uniform conditions of salinity are encountered.

J. S. H.

GRAIN BOUNDARY EFFECTS AS A FACTOR IN HETEROGENEOUS EQUILIBRIUM OF ALLOY SYSTEMS.

BY

ARTHUR PHILLIPS* AND R. M. BRICK.†

During the last decade our knowledge concerning the structure of crystalline aggregates has been greatly increased by X-ray studies of a quantitative nature which have disclosed rather completely the atomic arrangement and interplanar distances of the common metals and alloys. Information of this type, however, pertains only to the structural characteristics of the crystalline material comprising the major part of the grain and does not ordinarily contribute in any way to our understanding of the constitutional conditions at the grain boundaries. Although the probable form of discontinuity of these contact areas has long been a matter of speculation, there is at the present time no generally accepted theory regarding the arrangement of the atoms at the boundary regions. Furthermore, there is no evidence at hand which enables us to determine precisely the relative amounts of "ideal" lattice material and of the structurally modified material constituting the grain envelope.

It has been impossible to make direct observations on these highly localized zones; the experimental difficulties involved are mainly due to the limited amount of boundary substance and its intimate association with the grain proper. It seems obvious that enlightenment on this subject must necessarily be derived from the weight of evidence accumulating from indirect methods of studying the properties and effects of grain surface areas.

Metals, in the form ordinarily tested and best adapted for service requirements, are aggregates composed of many crystalline grains and, consequently, many boundary zones.

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† From a part of a dissertation to be presented by R. M. Brick to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

A single crystal, on the other hand, contains no boundary area if we disregard for the moment the possibility that unbalanced surface forces may constitute a significant boundary condition. Although considerable attention has been directed to the properties of single crystals, interest has been largely confined to observations on the crystallographic movements associated with plastic flow and to the determination of the stresses required to produce specific movements and ultimate fracture. In spite of the direct comparisons which may be made between the mechanical properties of single crystals and polycrystalline materials, no simple appraisal of boundary conditions and effects can be established due to certain variables of unquestionable significance. The properties of the polycrystalline metal are of course a summation of certain factors including grain size, shape, orientation as well as the cohesive qualities of the boundary material. Moreover, since the single crystal is anisotropic and polycrystalline metal is usually isotropic due to a random arrangement of the component grains, it is clearly of importance to adopt an experimental procedure which will not be rendered invalid by these significant variables.

Although direct experimental evidence is utterly lacking regarding the structural features at grain boundaries, indirect evidence of a circumstantial character indicates that the contact areas must differ in some respect from the enclosed lattice. We are content to accept this evidence for the present without dwelling on the probable nature of the difference, i.e., whether the boundary consists essentially of a distorted or otherwise altered lattice structure or is composed of a more or less haphazard arrangement of atoms displaying none of the characteristics of crystallinity. It occurred to the writers that in alloys showing limited solid solubility it might be possible to demonstrate an appreciable difference in concentration of the solute atoms in the two regions. Furthermore, if the solubility limits of the intra-granular and the boundary materials differ, one would expect that the solubility limits of any polycrystalline material would depend not only on the temperature but also on the grain size since the relative amounts of boundary and grain substance change markedly with the average grain size of the aggregate.

It seemed probable that a careful study of the grain boundary effect on certain constitutional relationships, such as solubility limits, might be of value in adding to our knowledge regarding the influence, if not the actual nature, of these contact areas. Moreover, recent improvements in precise X-ray methods for determining lattice parameter values seemed to present a promising procedure for the determination of relatively small differences in solubility. In approaching this subject, an experimental program was planned for investigating the solubility limits in single crystals of several sizes and polycrystalline aggregates chiefly by X-ray methods.

PREPARATION OF MATERIALS.

Any survey of alloy systems for the purpose of selecting the one best suited for an experimental program of this character obviously involves proper appraisal of many factors among which may be mentioned: (*a*) purity of component metals available. (*b*) freedom of alloys from gas reactions, (*c*) ease of varying and controlling the grain size within broad limits, (*d*) adaptability of material for X-ray studies of a precise nature, and (*e*) general knowledge of a fundamental nature regarding the constitutional relations of the system.

The aluminum-rich copper alloys seemed ideally adapted from most viewpoints and were therefore chosen for this work. High purity aluminum (99.97 per cent.) furnished by the Aluminum Company of America, and exceptionally pure cathode copper from the Raritan Copper Works were used for the preparation of all alloys. A copper-rich hardener alloy, containing 34.5 per cent. copper, served as the addition agent in making the alloys listed in Table II. These alloys were prepared by melting the aluminum in a graphite crucible heated by means of a gas-fired pot furnace, adding the calculated amount of hardener and stirring the melt vigorously with a carbon rod. Without loss of time the metal was cast into a slightly preheated iron mold, quenched immediately after solidification and transferred to an electric furnace for an homogenization treatment of four days at 540° C. The significant steps in preparing wire from the several homogenized cast alloys are summarized in Table I.

The wires (0.063″) were used in the preparation of:

TABLE I.

Treatment.	Dimensions.	No. of Passes.	Per Cent. Reduction.	Heat Treatment.
(1) Ingot.....	1"×1"×3"	—	—	Several intermediate anneals at 400° C.
(2) Hammered....	0.5" rod	—	80	
(3) Cold rolled....	0.35" rod	6	50	2 hrs. at 300° C.
(4) Cold drawn...	0.10" wire	16	92	2 hrs. at 300° C.
(5) Cold drawn...	.063" [a]	6	95	2 hrs. at 300° C.
(6) Cold drawn...	0.036" [b]	9	67	2 hrs. at 300° C.

[a] Used for X-ray studies.

[b] Used for conductivity measurements.

(*a*) fine grained polycrystalline wire, (*b*) coarse grained polycrystalline wire, (*c*) single crystal wire, (*d*) fine single crystal powder consisting of particles comparable in size to grains in (*a*), and (*e*) coarse single crystal powder comparable in size to grains in (*b*). As might be anticipated, some difficulty was experienced in ascertaining the proper technique required for producing the grain and particle sizes desired. For this reason, we are including in some detail the treatments finally adopted with satisfactory results.

(*a*) *Preparation of Fine-grained Wires.*—The cold drawn wires were heat-treated in one operation to attain full solution of the copper as well as to produce a relatively small and uniform grain size in the wires of different copper contents. The schedule outlined in Table II resulted in an average grain diameter of 0.20 mm.

TABLE II.

Alloy No.	Per Cent. Copper (by Weight).	Temperature.	Time.	Average Grain Diameter.
1	1.02	540° C. (quenched)	4 hrs.	0.20–0.25 mm.
2	1.94	"	4 hrs.	0.20–0.25 mm.
3	3.02	"	4 hrs.	0.20–0.25 mm.
4	4.05	"	12 hrs.	0.15–0.20 mm.
5	5.17	"	24 hrs.	0.15–0.20 mm.
6	5.65	"	24 hrs.	0.15–0.20 mm.

(*b*) *Preparation of Coarse-Grained Wires.*—Wires treated as in (*a*) were stretched 4 per cent., held for 48 hours at 540° C., and quenched rapidly to maintain full solution. Here again grain size of alloys (1–3) of lower copper content

averaged somewhat larger than in the higher copper alloys (4–6). The difference, however, was small and the average grain diameter of each wire was approximately 0.7 mm.

(*c*) *Preparation of Single Crystal Wires.*—Wires treated as in (*a*) were stretched 2 per cent. and quenched after heat treating for 5 days at 540° C. Although all of the material was not converted into single crystal form by this treatment, sufficient material for our purposes was obtained from the several duplicate wires of each analysis.

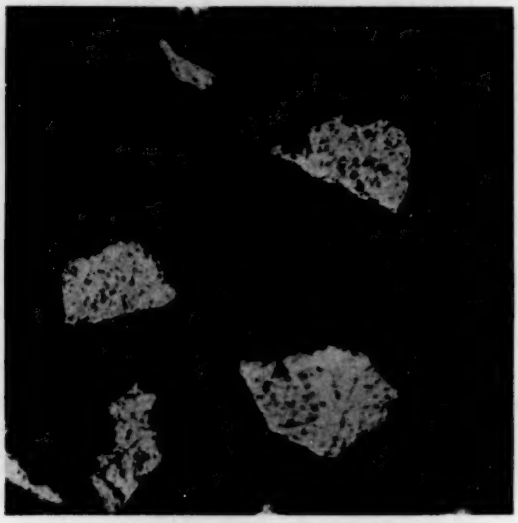
(*d*) *Preparation of Fine Single Crystal Powder.*—Fine particles, ranging from 0.07 to 0.10 mm., were prepared by screening filings removed from some of the single crystal wires by means of a fine file. It should be noted in this connection that the wires, in all cases, had previously been given a full solution treatment in order to avoid chemical heterogeneity in the powders prepared.

Preliminary experiments demonstrated that the strain produced by the filing was sufficient to promote subsequent grain growth of the nature desired. The powders were sealed in glass tubes after evacuating to a pressure of 0.02–0.03 mm. The sealed capsules were set in holes drilled in heavy brass blocks and annealed in an electric furnace for ten days at 540° C. At the end of this time the specimens were quenched by inverting the block over a tray of cold water. The brass block was of sufficient mass to prevent any appreciable drop in temperature of the powder during transference of the tubes from the furnace to the quench. The glass was shattered by contact with the water and the quenched powders recovered by decantation, and dried after rinsing in alcohol.

Samples of the quenched powder were mounted in sulphur, polished and examined microscopically. About 70 per cent. of the particles were found to be single crystals and the remainder consisted of two or at most three grains, Fig. 1 (*a*). It was necessary to preheat the powder for successful mounting thereby resulting in considerable precipitation of $CuAl_2$.

(*e*) *Preparation of Coarse Single Crystal Powder.*—Wires (0.036″) previously solution treated were stretched 2 per cent. and clipped with shears to give a powder which, after screening, had an average particle size of 0.6–0.8 mm. This material was sealed in evacuated tubes and treated as described in the

FIG. 1.



(*a*) Fine powder-alloy 2–250 ×.

(*b*) Coarse powder-alloy 2–50 ×.

(*a*) and (*b*) Typical structures of single crystal powders.

preparation of the fine powder single crystals. Upon examination it was found that powder specimens of alloys 1, 2, and 3 consisted essentially of single crystal particles, Fig. 1 (*b*), but that alloy powders 4, 5, and 6 were polycrystalline, generally containing 6–12 grains (see corresponding lattice parameter data, Fig. 4).

DESCRIPTION OF X-RAY METHOD AND DISCUSSION OF ERRORS INVOLVED.

A circular Debye-Scherrer camera of the van Arkel type with a diameter of 114.63 mm. was used for the X-ray investigation. The tube defining the X-ray beam extended to within 1/8″ of the specimen to ensure parallel radiation. The alloy wires were inserted in a specimen holder which was accurately set in the center of the camera. A clock mechanism was used to rotate the specimens. Single crystal powders were mounted by wrapping and cementing cellophane around the end of a wire of the same diameter as the polycrystalline specimens and filling the cylinder so formed with the powder. This resulted in a less fragile mounting than glass tubing, more closely controlled specimen diameter, and a shorter time of exposure. In both the wire and cellophane mountings the axis of rotation coincided with the axis of the specimen. Copper K-radiation from a Seemann X-ray tube operating at 40,000 volts with a tube current of 25 milliamperes was employed in making photograms. The exposure times were two hours for wire specimens and three hours for powders encased in cellophane.

Preliminary exposures of the same specimen at different room temperatures showed marked variations in the lattice parameter obtained. Consequently, during exposure, the camera was enclosed in a constant temperature box. The air within the box was thermostatically maintained at 24° C. ± 0.3° C. and the temperature of the specimen inside the camera must have varied even less.

The X-ray photograms, developed under closely identical conditions of time and temperature, were measured within 24 hours of the time they were dry. A microcomparator was used for measuring the (333) α_1 and (333) α_2 lines, reflecting at angles of from 80° to 84°, and the (422) α_1, at about 69° to 70°. Readings were taken in all cases at the middle of each line.

All of the single crystal wire specimens had orientations such that two spots from each reflecting plane lay very near the longitudinal axis of the film. By superimposing the film of the single crystal wire over one of a comparable single crystal powder with its sharply defined lines and reading with the magnifying microcomparator, it was possible to make an accurate projection of the single crystal reflection spots to the film axis. The change of lattice constant of the large single crystals with copper concentration was obtained in this way.

Previously a complete determination of the lattice changes in single crystals was made employing a Seifert camera of the Sachs type. Using this method we obtained uniform lines for single crystal reflections by placing the film on a flat holder which rotates at 250 r.p.m. Lattice parameters derived in this way were consistently 0.0008 Å. less than the values for the same specimens exposed in the van Arkel camera. The corrected values are in general agreement with the data obtained with the latter camera but have been omitted because of our inability to make direct comparisons.

The lattice constant was calculated from the well-known formula:

$$a = \frac{\lambda\sqrt{h^2 + k^2 + l^2}}{2 \sin \theta}, \tag{1}$$

where for copper radiation, the values used are: [1]

$$\lambda\alpha_1 = 1.53726 \text{ Å.},$$
$$\lambda\alpha_2 = 1.54116 \text{ Å.}$$

Values for θ for each reflecting plane were obtained from the film measurement by:

$$\theta = \frac{r}{2D}, \tag{2}$$

where r is distance between lines on film and D the camera diameter. From equation (1), the lattice constant error in terms of θ becomes:

$$\frac{\Delta a}{a} = -\cot \theta \cdot \Delta\theta, \tag{3}$$

[1] From Schleede and Schneider, "Roentgenspektroskopie," Berlin, 1929.

demonstrating the elimination of the θ error for a 90° reflection. From equation (2):

$$\Delta\theta = \frac{1}{2D} \cdot \Delta r, \tag{4}$$

which leads to the correction expression derived by van Arkel [2] for a circular camera:

$$\Delta a = C \cdot (90 - \theta) \cdot \cot \theta, \tag{5}$$

where C is a constant. Equation (5) was used in making the correction by plotting the calculated lattice parameter of each of the three lines against the corresponding value of the function $(90 - \theta) \cdot \cot \theta$ and extrapolating to $\theta = 90°$.

It is evident that the exact point of reflection cannot affect the corrected lattice parameter value. To demonstrate this fact more forcibly and also to show the method of applying the correction, the calculations for the fine polycrystalline wire specimen of alloy 6, diameter 1.6 mm., are reproduced in Table III. Assuming a similar specimen either displaced 0.2 mm. or of only 1.2 mm. diameter, Fig. 2, the changes in uncorrected values are found to alter the slope of the correction function so that extrapolation leads to the same corrected a_0 value, Fig. 3.

TABLE III.

Alloy 6. Solution Heat Treated—Fine Polycrystalline Wire.

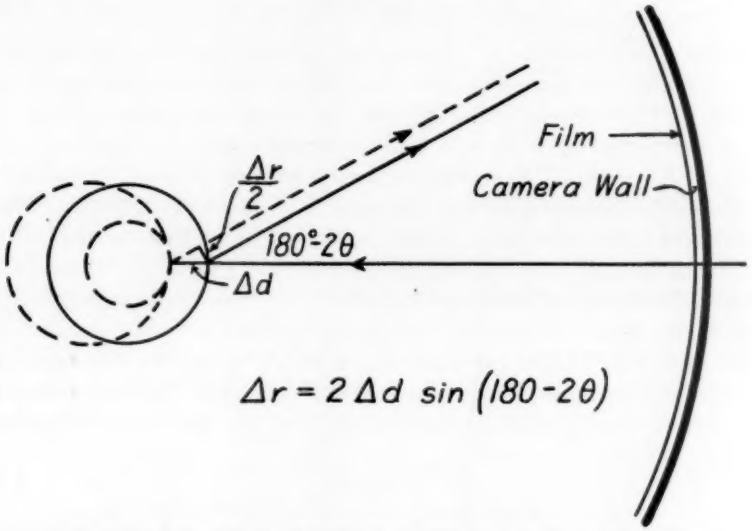
Spec. Diam.	Reflecting Plane.	r.	θ.	a.	$(90 - \theta) \cdot \cot \theta$.	a_0.
1.6 mm.	(422) α_1	82.26	69°26.2′	4.0218	7.72	
	(333) α_1	30.32	82°25.2′	4.0292	1.010	4.0303
	(333) α_2	25.74	83°33.8′	4.0295	0.731	
		$(r+\Delta r)$	$(\theta+\Delta\theta)$			
1.2 mm.	(422) α_1	82.52	69°22.2′	4.0235	7.77	
	(333) α_1	30.42	82°23.7′	4.0294	1.014	4.0303
	(333) α_2	25.83	83°32.6′	4.0296	0.733	

Thus the extrapolation to 90°, for the case of 80° to 85° reflections, eliminates or reduces to a negligible amount such errors as: slight eccentricity of the axis of rotation of the specimen, uncertain depth of penetration of the X-rays, inaccurate measurement of the effective camera radius, vari-

[2] A. E. van Arkel, Z. für Kristallogr., 1928, 67, 235.

ations in specimen diameter, shrinkage of film from development, imperfect flattening of the film on the camera wall, and inaccurate centering of the specimen. Variations in exposure temperatures which are an important source of error, particularly in these alloys of high thermal expansivities, have been eliminated by thermostatic control as previously described.

FIG. 2.



Effect of displacement of reflection position on the measured r value for any plane.

There remains the film measurement error. Each film was measured several times and the average distance employed in the calculations. In the fine polycrystalline and fine powder alloys, the maximum variation in different readings on the same film was $\pm$ 0.05 mm.[3] Combining equations (3) and (4) gives for the measurement error:

$$\frac{\Delta a}{a} = -\cot\theta \frac{1}{2D}\Delta r \sim 0.0027 \text{ per cent.}$$

[3] P. Wiest, Z. für Physik, 1932, **74**, 225, also obtained readings to within $\pm$ 0.05 mm. In our own work, the fine grained polycrystalline and fine powder materials gave sharply defined lines which were read with a normal variation considerably less than this figure.

or for pure aluminum

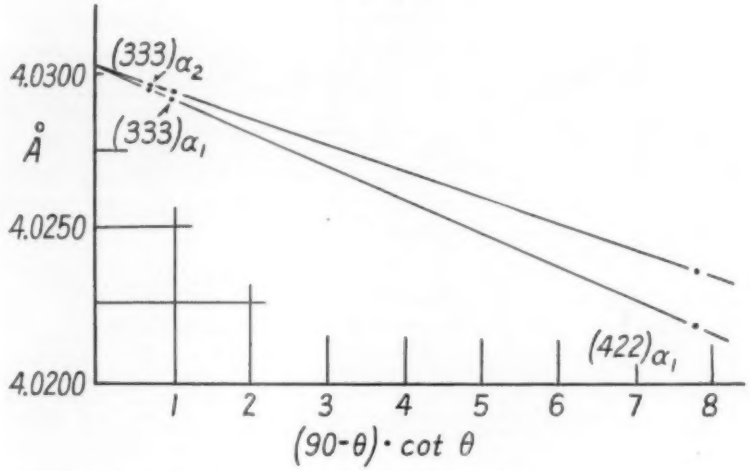
$$\Delta a = \pm 0.0001 \text{ Å}. \tag{6}$$

Films of the other specimens could not be measured with an accuracy much better than ± 0.10 mm. This results in an error of

$$\Delta a = \pm 0.0002 \text{ Å}. \tag{7}$$

The effect of these measurement errors on the correction formula, equation (5), may be calculated from the $\Delta\theta$ values

FIG. 3.



Effect of displacement of reflection position on the corrected lattice parameter value.

of Table III and the slope function, C, of Fig. 3. For the (333) reflections

$$\Delta a_{0(\Delta\theta)} = 0.00002 \text{ Å}.$$

Thus the errors given in (6) and (7) for "a" are substantially the errors for the corrected value, a_0, as well.

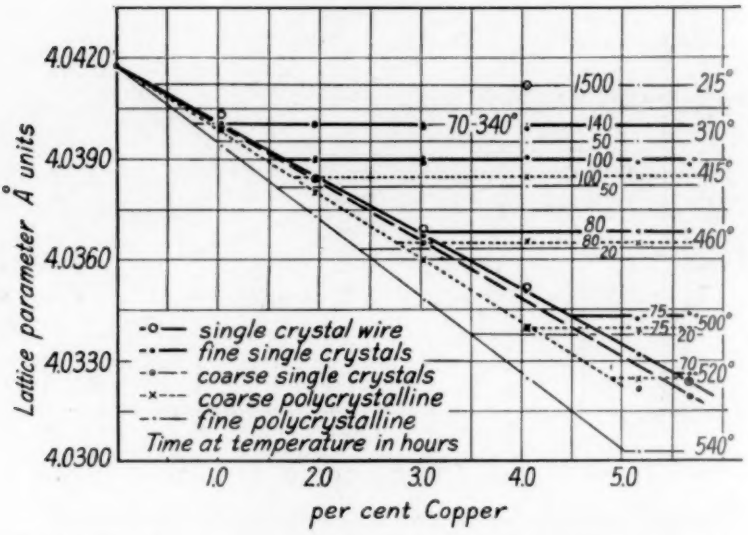
DETERMINATION OF THE CHANGE IN LATTICE CONSTANT WITH CONCENTRATION.

The lattice parameter values of the six alloys in both wire and powder conditions were determined promptly after quenching from 540° C., in order to eliminate any complica-

tions which might arise from room temperature ageing. The data obtained are presented graphically in Fig. 4.

Considering first the line representing the change in lattice constant with concentration * for the two polycrystalline alloy series, we note that the parameter of aluminum is decreased as a linear function of the copper concentration. Furthermore, the progressive shrinkage conforms closely to the theoretical values derived from Vegard's law. As a matter of fact, a line based on his formula lies

FIG. 4.



The lattice parameter data used in determining the solubility limits of the several materials.

about midway between our lines for the polycrystalline and single crystalline material. As far as we are aware, Göler and Sachs [4] are the only investigators who have published an l.c.c. line for the aluminum-rich copper alloys. Their line is placed somewhat under ours although three of their values agree very closely with our determinations on the fine polycrystalline wire.

* Subsequently referred to as the l.c.c. line.

[4] von Göler and G. Sachs, Metallwirtschaft, 1929, 8, 671.

Turning now to the values obtained on the three single crystal materials it is interesting to observe that, irrespective of the size of the crystals, the parameter values are substantially the same for equivalent copper concentration. We feel justified in assuming that the slight differences in values between the single crystal wire and the coarse powder series may be attributed to the fact that we were not successful in converting all of this material into single crystalline form. Apparently the X-ray data confirm the microscopic evidence of failure in this respect. It is especially significant that the parameter measurements of the single crystal wires are in good agreement with the corresponding values for the fine powders which, it will be recalled, consisted largely of single crystals. This suggests that unbalanced surface forces have no effect on the lattice dimension comparable to that of grain boundary areas.

A comparison of the several l.c.c. lines (Fig. 4) indicates that, for identical copper content, the lattice constant of a single crystal of any size is larger than that of a polycrystalline aggregate. This observation naturally suggests the probability of grain boundary influence inasmuch as the boundaries in the polycrystalline metal constitute the most obvious difference between the two forms of the same alloy. Moreover, it is pertinent to note in this connection that the l.c.c. line for the coarse polycrystalline wire, necessarily containing fewer boundaries than the fine grain wire, lies between the two limits. As far as we are aware, this has not been shown in the work of other investigators.

As this work was in progress, Wiest [5] published the results of his studies on copper-rich silver alloys, in both single crystalline and polycrystalline forms. According to Wiest, for a given silver content, the polycrystalline material had the larger parameter (Fig. 6). It should be noted in this connection that, up to the solid solubility limit, silver expands the copper lattice whereas copper shrinks the aluminum lattice. Wiest's results have been questioned by E. Schmid and Siebel,[6] who reported that they found no grain size effect in their studies on Al-Mg, Mg-Zn, and Mg-Al alloys. We

[5] P. Wiest, loc. cit.

[6] E. Schmid and G. Siebel, Metallwirtschaft, 1932, 11, 685.

are especially interested in their assertion that E. Schmid and G. Wasserman were unable to find significant differences in parameter values of single crystal and polycrystalline aluminum alloys containing 5 per cent. copper.

It was considered desirable to obtain further evidence of another character, i.e., other than by X-ray methods, confirming the parameter difference noted in alloys differing only in grain size. Since the alloys examined were solid solutions with no precipitated compound present, it was concluded that the rather considerable lattice value differences would be associated with density changes sufficiently pronounced to be detected by determinations of a precise nature. Specimens containing 2 per cent. copper showed without question a decreasing density with increasing grain size. The results of many density tests on aluminum and aluminum-copper alloys of varying grain sizes will be published at a later date.

Let us assume for the moment that the parameter value of a single crystal of a given copper content represents the lattice dimension for that atomic concentration of copper. In other words, a change of the aluminum lattice has been effected solely by the introduction of copper atoms without any disturbance of the equilibrium by boundary forces or conditions. The question then arises as to whether differences in copper concentration between boundary areas and grain proper may account for the lower parameter values of the polycrystalline alloys. Turning again to the l.c.c. lines of Fig. 4, we note that the 4 per cent. alloy in the polycrystalline state has a parameter value of 4.0326 Å. The same lattice measurement in a single crystal requires the solution of 5.5 per cent. copper. Since the parameter values obtained by the X-ray measurements are based on the reflections from the grain lattice (i.e., not the boundary areas) and if we assume that equivalent solute concentrations give identical lattice values, it would appear that the grain areas, exclusive of the boundary area, contain 5.5 per cent. copper. A simple calculation shows, however, that in order to attain this concentration of copper in the grain-lattice, a surrounding boundary envelope representing 27 per cent. by volume of the total aggregate would be entirely depleted of copper. It is obvious that no local depletion of this magni-

tude could be considered within the realm of possibility. This analysis by no means denies the existence of local differences in concentration between grain-lattice and boundary areas but simply indicates that the lattice parameter differences between the polycrystalline and single crystal alloys are in some way attributable to boundary effects of an unknown nature.

We may appropriately refer at this time to determinations of the a_0 value for pure aluminum. Although Göler and Sachs did not specifically state the results of their determination on 99.95 per cent. aluminum a value of 4.040_3 Å. may be read from their plot. Gayler and Preston [7] give 4.0412 $\pm$ 0.0004, while, more recently, Nishiyama [8] and Owen and Iball [9] report 4.041 and 4.040_6 respectively. Our own result, based on the average of several closely agreeing determinations, gives 4.0418 $\pm$ 0.0001 (24° C.) for unusually pure aluminum (99.97 per cent.). This value is confirmed by extrapolation of our l.c.c. lines to zero per cent. copper.

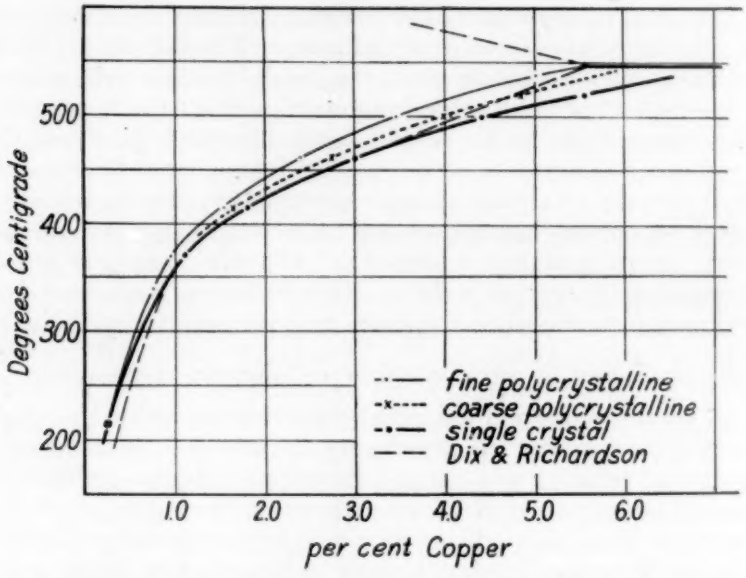
DETERMINATION OF SOLID SOLUBILITY AT DIFFERENT TEMPERATURES.

The X-ray method was now utilized to determine the solid solubility of copper in aluminum at different temperatures after heat treating some of the alloys to establish equilibrium in the two phase region. In this work, homogeneous solid solutions were heated at successively lower temperatures ranging from 540° to 215° C. and then quenched. The heat treatments were made in the manner previously described except for the 215° C. treatment for which the specimens, sealed in glass capsules, were immersed in a nitrobenzene bath fitted with a reflux condenser. Great care was taken to ensure attainment of equilibrium at each temperature, the treatment being continued until no further change in lattice constant was noted. In general, it may be said that the time required for complete precipitation in the single crystals was much longer than in polycrystalline alloys of the same composition. This observation is in accord with the data of Wiest and others. The total time of heat treatment for each

[7] M. L. V. Gayler and G. D. Preston, *J. Inst. Metals*, 1929, **41**, 191.
[8] Z. Nishiyama, *Sci. Rep. Tôhoku Imp. Univ.*, 1932 (1), **21**, 364.
[9] E. A. Owen and J. Iball, *Phil. Mag.*, 1932 (VII), **13**, 1020.

saturation limit is shown on the temperature horizontals of Fig. 4. The amount of copper in solution at any given temperature determines the lattice parameter of the saturated solid solution in equilibrium with the precipitated phase. Solubility lines based on these measurements are shown in Fig. 5.

FIG. 5.



Solubility temperature-concentration limits for the materials of different grain characteristics.

It is interesting to compare the solubility limits established by the X-ray method with the curve based on the extremely careful microscopic analysis of Dix and Richardson.[10] Two minor differences may be noted, (1) above the "knee" of the curve we have found a continuous curvature towards the eutectic horizontal instead of the straight line prolongation shown by Dix and Richardson, (2) their curve indicates a solubility at 250° of 0.5 per cent. copper whereas our results point to approximately 0.30 per cent. at that temperature with an indication of zero solubility at room temperature. It will be noted that our solubility line for the fine poly-

[10] E. H. Dix and H. H. Richardson, *Trans. A. I. M. M. E.*, 1926, 73, 560.

crystalline material intersects the eutectic horizontal (548°) at the same point as Dix and Richardson's line (5.6 per cent. copper). Extrapolating the single crystal line to the same eutectic temperature would result in a solubility limit of about 7 per cent. copper. It may be suggested that since grain size is a factor in solubility temperature-concentration limits, the eutectic temperature may vary with the size of the component grains.[11] For this reason we have not completed the extrapolation to an eutectic horizontal.

Although our solubility limits are somewhat lower than those reported by Dix and Richardson, we are not at all inclined to question the accuracy of their work. It is quite possible that the slight discrepancy may be attributed to the difference in the methods used to establish these limits. We determined the parameter of the solid solution in equilibrium with the precipitated $CuAl_2$. Since only alloys relatively high in copper were used, the heat treatments precipitated a large amount of $CuAl_2$. It is evident that a boundary of some kind exists between the solid solution and the compound. R. F. Mehl,[12] in discussing the separation of $CuAl_2$ states ". . . the nucleus becomes a new phase, separated from the matrix phase by an interface or grain boundary." Although it is readily conceded that the boundary in this case surrounds the $CuAl_2$, nevertheless it is possible that the considerable amount of compound present furnishes a more or less continuous boundary at least partially enclosing relatively small fragments of the matrix solution. In other words, the precipitation of the $CuAl_2$ may add boundary areas to both single and polycrystalline metal and as the amount of compound increases the relative difference in boundary areas of the two materials may therefore decrease. Thus, although the X-ray photograms indicated an unaltered single crystal even with large amounts of precipitate present, it may not retain all the properties of a true single crystal. If the influence of this boundary condition is comparable to that of

[11] According to Edwards, Frary and Jeffries, "The Aluminum Industry" (1930), the freezing point of a fine-grained eutectic of aluminum and silicon is 564°, while a normal coarse eutectic freezes at 577° C.

[12] R. F. Mehl, C. S. Barrett and F. N. Rhines, *Trans. A. I. M. M. E.*, Inst. Met. Div., 1932, **99**, 203.

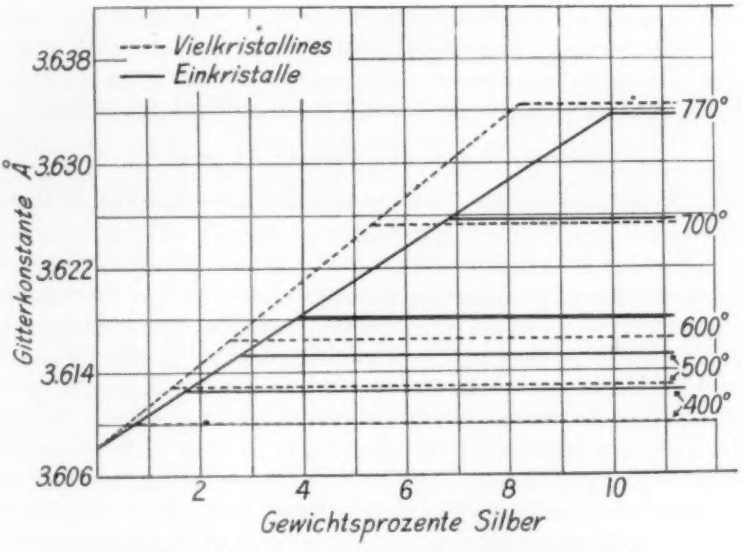
normal grain boundaries, our solubility lines may be located too far to the left, i.e., to lower copper concentrations. Dix and Richardson, on the other hand, necessarily examined alloys where little or no $CuAl_2$ was precipitated at each temperature investigated. Hence no marked alteration of the boundary characteristics of their alloys could occur and their results may be a true index of solubility for the grain sizes of the alloys investigated.

It is appropriate at this time to mention another factor which may have a significant influence on the temperature-concentration solubility limits. We refer to the particle size of the $CuAl_2$ in equilibrium with the solid solution. Our results on single crystals suggest that the greater the amount of $CuAl_2$ precipitated for any given temperature the nearer the lattice parameter approaches that of polycrystalline material even though the X-ray photogram shows no breakdown of the single crystal. The effect of the $CuAl_2$ particles on solid solubility may be caused by the boundary condition discussed above or on the other hand it may conform specifically to the Kelvin-Oswald-Freundlich law which deals with the relation between solubility and particle size of the solid solute. Thus it is possible that one or both of these effects may account for the convergence of our solubility lines at the lower temperatures. In order to minimize the errors which may arise from lattice parameter measurements of solid solutions in equilibrium with relatively large amounts of solid solute, it may be generally advisable to establish the limits of solubility with alloys containing only a small amount of precipitated solute at the temperature employed.

Our results indicate a difference in parameter values between single crystals, coarse and fine polycrystalline materials for all temperatures investigated. The difference occurs in the same direction, but not to the same extent, for both single and two phase conditions. Wiest's work on the copper-silver series shows a smaller lattice constant for single crystals than for polycrystalline materials of the same composition in the solid solution form (Fig. 6). As a result, the slope of the l.c.c. line is less for the single crystals, as found in our work. In the two phase field at 700° C. and above, the lattice constant is the same for both materials. However, at

about 600° C. and below, he again finds differences in parameter values but opposite in direction to those found in the homogeneous solid solutions. No simple explanation is apparent for this reversal in Wiest's alloys. It does, however, account for the general parallelism of the single and polycrystalline solubility lines, particularly at low temperatures. No similar reversal of the parameter differences was noted in our work and, as mentioned before, the several solubility lines tend to converge into one at the lower temperatures.

FIG. 6.



Reproduction of Wiest's lattice parameter data on the copper-silver alloys.

Conductivity tests at elevated temperatures furnished evidence in confirmation of the solubility differences found by the X-ray method. Pure aluminum wire (used as a control) together with three alloy wires of the same composition but of distinctly different grain sizes were placed in a furnace designed for this purpose. Resistivity measurements were made by means of a Type K Leeds and Northrup precision potentiometer. After heating the wires to 540° C. to obtain complete solution of the $CuAl_2$, the temperature was lowered by predetermined steps. The wires were held at each tem-

perature for approximately 100 hours to ensure equilibrium conditions. Although only a limited number of determinations were made in this way, the results were in good agreement with the solubility behavior shown in Fig. 5. For example, in a 4 per cent. copper alloy, a marked drop in resistivity at 502° C. indicated some precipitation of $CuAl_2$ in a medium size grain (0.4–0.6 mm.) wire. No comparable change was noted in the "single" crystal wire until 492° C. was reached, at which temperature a significant decrease in resistivity denoted the beginning of precipitation.

Another method which naturally suggests itself for the determination of solubility differences of the order shown by the X-ray study is that of microscopic analysis. We have planned an experimental program which involves a careful study of high-copper content alloys of several grain sizes.

SIGNIFICANCE OF GRAIN BOUNDARY EFFECTS.

The work of Wiest and the present investigation indicate that the grain boundary factor may be of fundamental importance in establishing constitutional relationships. If these results are confirmed by subsequent studies, we venture to predict that grain size effects, previously viewed as of theoretical interest only, will acquire a practical significance.

For example, Bain [13] has recently stated that ". . . effective grain size (austenite) seems to be the most potent single factor influencing hardenability"; also, "the finer the grain size, the more rapid is the transformation to fine pearlite, and correspondingly the lower is the hardenability." It is interesting to note Bain's conclusion that coarse-grained steel is essentially a deep hardening steel, while fine grained steel is a shallow hardening steel. The importance of boundary area effects and the associated solubility relationships may be properly considered in connection with Bain's work on hardenability of steel.

Again, it is entirely possible that the fragmentation produced by severe cold working may have an important effect on the solubility limits of certain alloys. The fragmented grain size after drastic treatment is, of course, of an entirely different order in comparison with the minimum size

[13] E. C. Bain, Campbell Memorial Lecture A. S. S. T., 1932, **20**, 385.

considered in this investigation. One can only speculate regarding the nature and effect of the boundaries of the fragmented particles. Such boundaries may be fundamentally different from the boundaries present in cast and annealed metals, and may indeed have no significant effect on solution limits. Further experimental work in this direction seems desirable.

Finally, it is obvious that if grain boundary areas are a significant factor affecting solubility limits, for the attainment of complete solution, a temperature must be chosen with proper regard for the grain characteristics of the material. This is particularly true if observations of a critical nature involving precipitation hardening effects are contemplated. It is pertinent in this connection to review the experiments reported by Karnop and Sachs [14] on single and polycrystalline aluminum copper alloys, containing 5 per cent. copper and prepared with high purity aluminum. They observed that after quenching both materials from 525° C. and ageing at 100° C., single crystals of all orientations tested possessed higher values of yield point and strength. Furthermore, they noted that ". . . hardening starts earlier and is greater with single crystals than with finely crystalline material." Our solubility lines indicate that to effect full solution for this alloy in single crystal form, a minimum temperature of 515° C. is essential, and that for polycrystalline material a temperature of 540° C. must be reached. Assuming our data are correct, it is apparent that the temperature (525° C.) employed by Karnop and Sachs for the solution treatment lies about midway between the two solubility lines. Full solution was, therefore, attained only for the single crystals.

[14] R. Karnop and G. Sachs, Z. für Physik, 1928, **49**, 480.

A Scientific Adventure.—Under this title, GEORGE E. VINCENT (Barnwell Bull., 1933, X, No. 42, 5–23) describes the warfare against yellow fever which has been waged by the Rockefeller Foundation since 1916. In 1881 Carlos Finlay of Cuba had developed the hypothesis that yellow fever is communicated by the stegomyia mosquito (*Aedes Aegypti*). In 1900 Walter Reed and his colleagues proved conclusively the correctness of this hypothesis; and Gorgas eradicated the disease from Havana and Cuba. For 140 years yellow fever had been endemic in Guayaquil, Ecuador. In November, 1918, Connor began to combat the disease there; all water tanks were covered with copper screens of 16 mesh to the inch; and fish were placed in other water containers to consume the eggs and larvæ of the mosquito. That month 81 cases of yellow fever developed; during each of the seven following months the number of new cases was 88, 81, 47, 17, 3, 2, and 0, respectively. Since then, not a case has developed. Various outbreaks on the American continents have been controlled. In 1927 rhesus monkeys of India were found susceptible to yellow fever, and suitable animals for its laboratory study. Laboratory work has demonstrated that the African and the American forms of the disease are identical, for an immune serum from Africa protected a susceptible monkey from the action of the virus from South America. Several other mosquitos, distant relatives of stegomyia, may also communicate the disease but do not do so to any considerable extent. In a mild form, yellow fever is widespread among the natives in Africa, a fact which greatly increases the difficulty of its control. The ignorance, superstitions, and suspicious attitude of the natives, and the matter of expense all further complicate the problem. A very serious possibility exists of the transmission of yellow fever from Africa to the Far East as transcontinental air service is developed in Africa.

J. S. H.

THE STRUCTURE OF UNIMOLECULAR FILMS.

II. SURFACE FILMS OF PROTEINS.

BY

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(Cancer Research Laboratories, Graduate School of Medicine, University of Pennsylvania.)

Surface films one molecule in thickness present the simplest type of molecular mosaic. In this paper, data obtained by means of surface pressure and surface potential methods on films of various proteins are given and applied in an attempt to indicate the probable structure of the protein micelle as it exists in the film state. Gorter and Grendel [1] were the first, with the aid of a Langmuir trough, to examine thin films of proteins and spread the material dispersed in acid or alkaline solutions on the surface of various substrates. This method, ingenious as it was, could not be utilized to obtain homogeneous films in every instance as revealed by the ultramicroscopic examination of protein films spread in this manner by Zocher and Stiebel.[2] The apparent mean limiting thickness of the films studied by Gorter and Grendel varied from 7.5 to 30.0 Å. and appeared to be complicated by the action of the dispersing agent on the proteins and the solubility of a portion of the material.

Preliminary results on some protein films have been presented by Hughes, Schulman and Rideal.[3] Recently Hughes and Rideal [4] have examined in detail the behavior of monolayers of gliadin and glutenin. Films formed by spreading the solid material directly from the arm of a quartz fiber microbalance were found to be homogeneous as revealed by surface potential and surface pressure measurements. In the case of gliadin, in which two-thirds of the side chains may be regarded as consisting of the glutamyl residue, they were

[1] *Trans. Far. Soc.*, **22**, 477 (1926).
[2] *Z. für physik. Chem.*, **147**, 401 (1930).
[3] *Nature*, **129**, 21 (1932).
[4] *Proc. Roy. Soc.*, A, **137**, 62 (1932).

able to assign a simple zig-zag type of structure for the film in various stages of compression.

Svedberg and his collaborators have shown, as a result of the ultra-centrifuge studies, that remarkable uniformity occurs in the repetition of a unit of particle mass in certain soluble proteins. Classes of molecular weight 1, 2, 3 and 6 times the common unit 34,500 have been shown to exist.

The isodisperse proteins appeared to be quite suitable for thin film studies, inasmuch that one would expect to find a dimensional and colligative regularity to be displayed with increasing molecular weight.

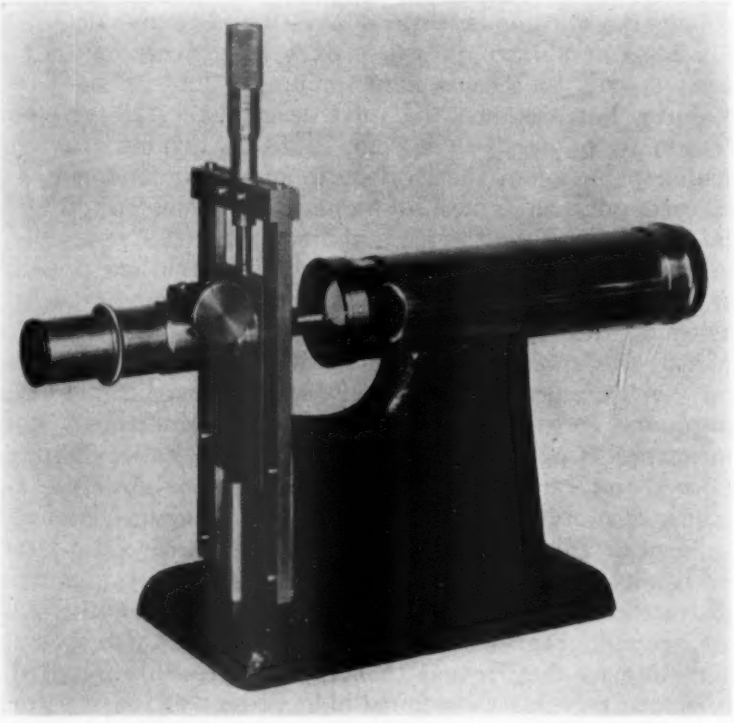
EXPERIMENTAL PROCEDURE AND RESULTS.

The spontaneous spreading of a particle of solid protein, when placed on the surface of an aqueous solution, provided a simple and convenient method for obtaining uniform monolayers.

In order to obtain quantitative data on the films it was necessary to weigh the minute quantity of protein, generally about 5×10^{-5} grams, with reasonable accuracy. The quartz fiber microbalance shown in Fig. 1 was devised for this purpose. Many types of microbalances having sensitivities to 1×10^{-10} grams are described in the literature but they do not fulfill the requisites desired for film studies. The balance to be described had an average sensitivity of 1×10^{-6} grams per 0.01 mm. deflection and permitted the removal of the fiber from the balance case in order to spread the protein. It consisted of a quartz fiber approximately 0.09 mm. in diameter and 10 cm. in length, one end of which was firmly cemented by means of rosin to an accurately machined steel rod 12 mm. in diameter and 8 cm. in length. To the other end of the fiber was attached a very thin glass scale pan about 3 mm. on the edge. A very thin quartz cross-hair, cemented immediately in back of the pan, served to indicate the position of the fiber. To provide a surface on which the protein could be dusted the glass scale pan was given a thin coating of wax by dipping into a dilute hexane solution of paraffin. The displacement of the fiber, caused by placing a small quantity of protein on the pan, was determined by the telescope fitted with an ocular micrometer.

The instrument was calibrated by placing a small weight on the pan and noting the deflection. In the spreading of proteins from the fiber, the desired quantity was placed on the pan, then slightly moistened by steaming, and the entire amount allowed to spread. By placing the fiber under a slight elastic tension when in contact with the surface, uniform spreading proceeded with gradual immersion of the pan (Fig. 1).

FIG. 1.



The surface pressures of films formed in this manner were measured with the aid of a Langmuir trough of the type employed by Adam and Jessop [5] and surface potentials were determined by a method previously described by the authors.[6]

[5] *Proc. Roy. Soc.*, 110, 423 (1926).

[6] Fosbinder and Lessig, this number J. F. I.

For the surface potential measurements the buffer solutions were prepared according to Clark[7]; triple-distilled grease-free water being used as the solvent.

A. Force-Weight Measurements.

A preliminary examination revealed that egg albumen, serum albumen, pepsin, trypsin, and casein spread spontaneously on the surface of $N/100$ HCl and on buffer solutions varying in pH from 2.4 to 9.4. The rate of spreading on the buffer solutions was considerably slower than on the acid. Proteins classified as isodisperse were found to give definitely solid films at surface pressures of 3 to 4 dynes/cm., while casein spread to form a film definitely fluid at moderate pressures, but assumed the solid or gel like state on compression to 13 or 14 dynes/cm. Edestin exhibited a most peculiar behavior in that a definite spreading tendency was observed only on buffer solutions which were either more acid or alkaline than the pH stability range.

For the purpose of obtaining preliminary surface pressure data a small but unknown quantity of protein was lightly dusted on the paraffin covered surface of a glass rod from which it was spread by contact with the surface of the solution. When a perceptible pressure was observed the film was compressed and the force noted for each area setting. Since the reciprocal of the area is proportional to the weight per sq. cm., information regarding the compressibilities and packing of protein films may be obtained from F, $1/A$ curves as shown in Table I.

From the limiting values of $1/A$ it is seen that on a given substrate all of the proteins occupied approximately the same area per milligram. The values obtained for the slopes are interesting as they reveal that the compressibilities of the isodisperse proteins were fairly independent of the substrate pH, while that of casein, a polydisperse protein, decreased with increasing pH, indicative of a marked alteration in the adhesion of the polar groups for the substrate. In the determination of the F, $1/A$ characteristics it was observed

[7] "The Determination of Hydrogen Ions," Williams and Wilkins, Baltimore (1928).

TABLE I.

Temperature 15° C.

Protein.	Substrate.	pH.	Slope $\frac{F}{1/A} \times 10^4$.	$1/A \times 10^3$ at 0 Compression.
Pepsin	HCl	2.0	2.04	1.7
Egg albumen	"	"	2.00	2.0
Serum albumen	"	"	2.00	2.0
Edestin	"	"	0.93	2.0
Casein	"	"	1.40	2.2
Egg albumen	Citrate-phosphate	6.4	1.85	1.7
Trypsin	"	"	1.47	1.9
Casein	"	"	0.82	1.6
Serum albumen	Phosphate	7.1	2.04	1.7
Pepsin	"	"	1.80	1.7
Egg albumen	Borate-carbonate	9.4	1.54	1.7
Pepsin	"	"	1.62	1.7
Serum albumen	"	"	2.00	1.7
Trypsin	"	"	1.56	1.9
Casein	"	"	0.71	1.7

that although the equilibrium spreading pressure, obtained with an excess of protein on the surface, was only 12 dynes/cm. a linear curve was obtainable for surface pressures greatly exceeding this value.

For the proteins egg albumen, serum albumen, and edestin, the slope of the force-weight curves was found to attain a maximum value at a surface pressure of ca. 3 dynes/cm. and an average surface concentration C of 1.43×10^{-7} gm./sq. cm., the films becoming gelatinous at this point. On compression to 20 dynes/cm. with C increasing to 2.40×10^{-7} gm./sq. cm. a linear increase in surface pressure was observed. At higher pressures the slope decreased due to gradual rupture of the film.

The values of the limiting surface concentrations obtained from the force-weight curves and the corresponding film thicknesses are given in Table II.

It is doubtful whether the values of δ have a real significance for they were computed on the assumption that the density of the protein in the film was identical with that in the bulk phase.

TABLE II.

Temperature 25° C.

Protein.	Surface Concentration for Linear Force-Weight Curve. $C \times 10^{-7}$ gms./sq. cm.		Film Thickness Å. (10^{-8} cm.). δ	
	Minimum.	Maximum.	Min.	Max.
Egg albumen	1.52	2.40	11.4	18.0
Serum albumen	1.54	2.53	11.5	19.0
Edestin	1.23	2.29	9.2	17.0
Average	1.43	2.41	10.7	18.0

If the material comprising the film is assumed to have the molecular weight obtained by ultra-centrifuge measurements, the limiting area per molecule may be computed from the value of the minimum surface concentration. Table III shows the molecular area obtained for several proteins on various substrates.

TABLE III.

Temperature 25° C.

Protein.	Substrate.	pH.	Area per Molecule at o Compression. Å².
Edestin	Citrate-phosphate	2.4	28000
Serum albumen	"	"	7500
Serum albumen	Phosphate	7.1	7300
Egg albumen	HCl	1.0	2800
" "	Citrate-phosphate	2.4	2800
" "	"	3.4	3800
" "	"	4.4	3700
" "	"	5.4	3750
" "	"	7.4	2750
" "	Phosphate	7.1	2700
" "	Borate-carbonate	9.4	2600

A comparison of the limiting values reveals that the maximum molecular areas vary directly with the molecular weights of the respective proteins. The variation in the limiting area of the egg albumen molecule on substrates of different pH cannot be reasonably explained unless hydration of the molecule is considered, for it is not due to an alteration in adhesion brought about by ionization of the free polar groups in view of surface potential measurements.

B. Surface Potential Measurements.

Values obtained for the change in surface potential (ΔV) caused by the presence of protein films on the various substrates are given in Table IV. The films were formed by placing an excess of the material on the surface.

TABLE IV.

Temperature 25° C.

Protein.	Substrate.	pH.	Average ΔV (mv.).
Egg albumen	HCl	2.0	331
Pepsin	"	"	269
Egg albumen	Citrate-Na_2HPO_4	2.4	344
Pepsin	"	"	261
Pepsin (crystalline)	"	"	268
Edestin	"	"	340
†Casein	"	"	372
Serum albumen	"	"	365
Trypsin	"	"	350
Egg albumen	NaOH-citrate	6.4	254
" "	Phosphate	7.1	253
* " "	"	"	263
†Trypsin	"	"	190
†Casein	"	"	286
Serum albumen	"	"	253
Egg albumen	"	8.0	247

* 30° C.

† Liquid Films.

On acid substrates the values of ΔV were considerably larger than on weakly acid or alkaline buffers. The increase in the values of the surface potentials ca. 95 mv. on acid solutions may be ascribed to a greater alteration in the zero potential caused by the film, a small increase in the molecular electric moment, and a larger surface concentration at equilibrium spreading pressure. It is of interest to note that all "gel" films gave approximately identical values of ΔV on the same substrate. The values of ΔV for pepsin and trypsin films on substrates having a pH corresponding to maximum activity of the enzyme in the bulk phase were observed to differ considerably from those obtained for other proteins. Perhaps this may be indicative of the presence of active centers on the surface of the enzyme.

To determine the value of the vertical component of the molecular electric moment ($\bar{u}$) it was necessary to follow the same general procedure used in obtaining the force-weight curves.

As shown in Table V, on a citrate substrate pH 2.4 fluctuating values of the potentials were obtained, indicative of a heterogeneous film until the surface concentration (C) reached 1.31×10^{-7} gm./sq. cm.

TABLE V.

Temperature 25° C.

Protein.	Surface Concentration Range for Linear ΔV, C Curve $C \times 10^{-7}$ gms./sq. cm		
Egg albumen	1.31	—	2.16
Serum albumen	1.32	—	1.79
Edestin	1.30	—	1.85
Average	1.31		1.93

On further compression to an average C of 1.93×10^{-7} gm./sq. cm. a linear increase in ΔV was noted. At higher surface concentrations the slope gradually decreased and ΔV attained a maximum value ca. 50 mv. greater than that observed in Table IV. On substrates of pH 4.4, 7.1 and 11.0 the ΔV, C curves for egg albumen were linear between the same limits but the maximum potential values were about 90 mv. lower.

The change in the surface potential may be expressed by:

$$\Delta V = 4\pi n\bar{u} + \Delta Vu,$$

where n is the number of dipoles/sq. cm. of vertical component $\bar{u}$ and ΔVu the alteration in the zero potential due to the presence of the film.

From the slopes of the ΔV, C curves and the molecular weights one may compute values for the vertical component of the electric moment of the protein molecule. If the approximate composition of the molecule is known then the electric moment per CO·NH·CHR unit may also be computed. The values of the derived moments are given in the following table.

The values of the electric moment per CO·NH·CHR are approximately one half of that obtained by Hughes and

TABLE VI.
Temperature 25° C.

Protein.	Substrate.	pH.	Mean Electric Moment per Molecule $\mu \times 10^{17}$ e.s.u.	Mean Electric Moment per CO·NH·CHR $\mu \times 10^{19}$ e.s.u.
Egg albumen...	Citrate-phosphate	2.4	1.72	0.69
" " ...	"	4.4	1.72	0.69
" " ...	"	7.2	1.46	0.58
" " ...	Boric acid-borate	11.0	1.60	0.64
Serum albumen	Citrate-phosphate	2.4	3.88	0.77
Edestin.....	"	"	11.40	0.76

Rideal (4) for gliadin. From the composition of the proteins examined the resultant moment must be due mainly to the contribution of the dipoles of the free —COOH and —NH_2 groups in the side chains.

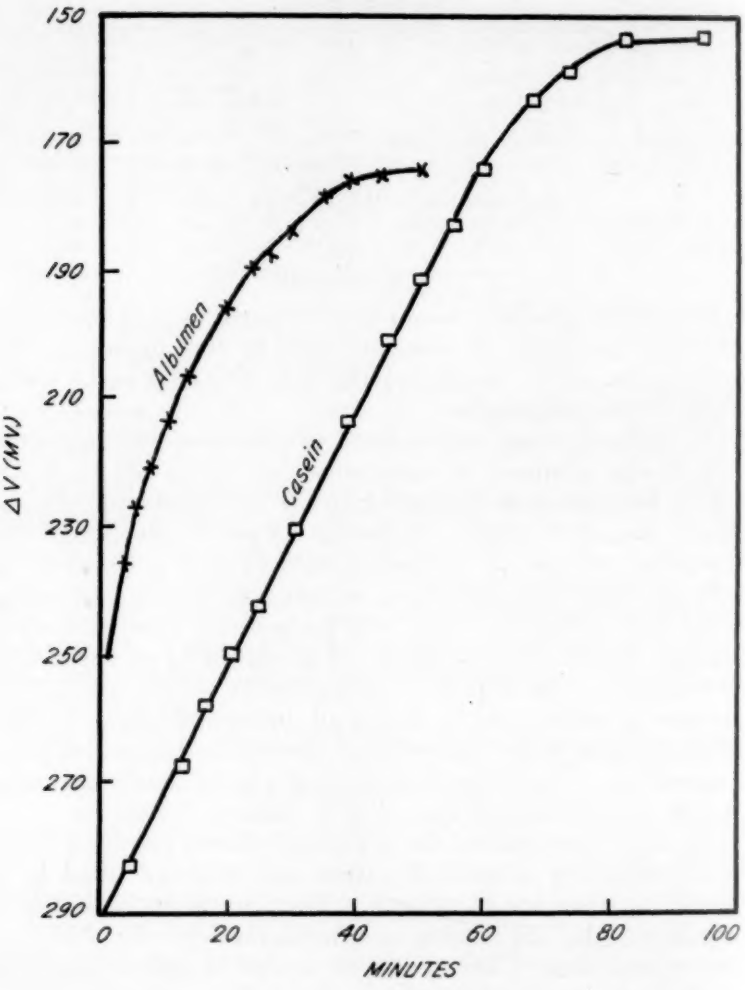
No difficulty was experienced in obtaining homogeneous films of egg albumen on substrates varying in pH from 2.4 to 11.0 but the same was not true for isodisperse proteins of higher molecular weight. Edestin, as previously noted, exhibited no tendency to spread on substrates of pH between 5 and 11.0, while serum albumen, although spreading somewhat, would not ordinarily form a homogeneous film on buffer solutions between pH 3 and 9. The similarity of the above pH ranges to the region of pH stability of the respective proteins is indicative of forces of intermolecular cohesion which are quite large compared to the surface forces operative in spreading. Just why the unit 34,500 is the maximum mass capable of spontaneous spreading is difficult to explain.

In Fig. 2 are shown the ΔV, time curves resulting from the digestion by trypsin of casein and albumen films on a phosphate substrate of pH 7.1. They are included in order to indicate the application of the method to the study of enzyme reactions. The curves show that complete digestion of the films occurred in about one hour. Apparently the hydrolysis of egg albumen was inhibited by reaction products present in the interface.

C. The Structure of the Films.

Definitely homogeneous films of egg albumen, serum albumen and edestin were obtained over a surface concentra-

FIG. 2.



tion range of 1.31×10^{-7} gms./sq. cm. to 1.93×10^{-7} gms./sq. cm. as indicated by the linear character of the ΔV, C curves. From force-weight data it was observed that a linear compression curve was obtained between the limiting values $C = 1.43 \times 10^{-7}$ gms./sq. cm. and $C = 2.41 \times 10^{-7}$ gms./sq. cm. The decrease in the slope of the ΔV, C curve

when the value of C exceeded 1.93×10^{-7} gms./sq. cm. is indicative of either interaction between the polar groups or of their gradual removal from the surface.

From the experimental observations, a knowledge of the constitution of the proteins, and available X-ray data it is possible to suggest a general structure for the "gel" films.

If the assumption is made that the fundamental structure of the protein molecule consists of the recurring basic unit,

$$—CO—NH—CHR—$$

then from an examination of the constitution of the proteins studied the average mass of the unit is found to be 120. In addition the average side chains to be considered and their respective masses are the following:

(1) $R = —CH_2—CH_2—CH_3$, 47

(2) $R = —CH_2—CH_2—CH_2—NH_2$, 58

(3) $R = —CH_2—CH_2—COOH$, 73.

A review of the hydrolysis products of the proteins examined reveals that on the average only 1 out of 3 side chains contains a strongly polar —COOH or $—NH_2$ group.

The length of the amino acid residue

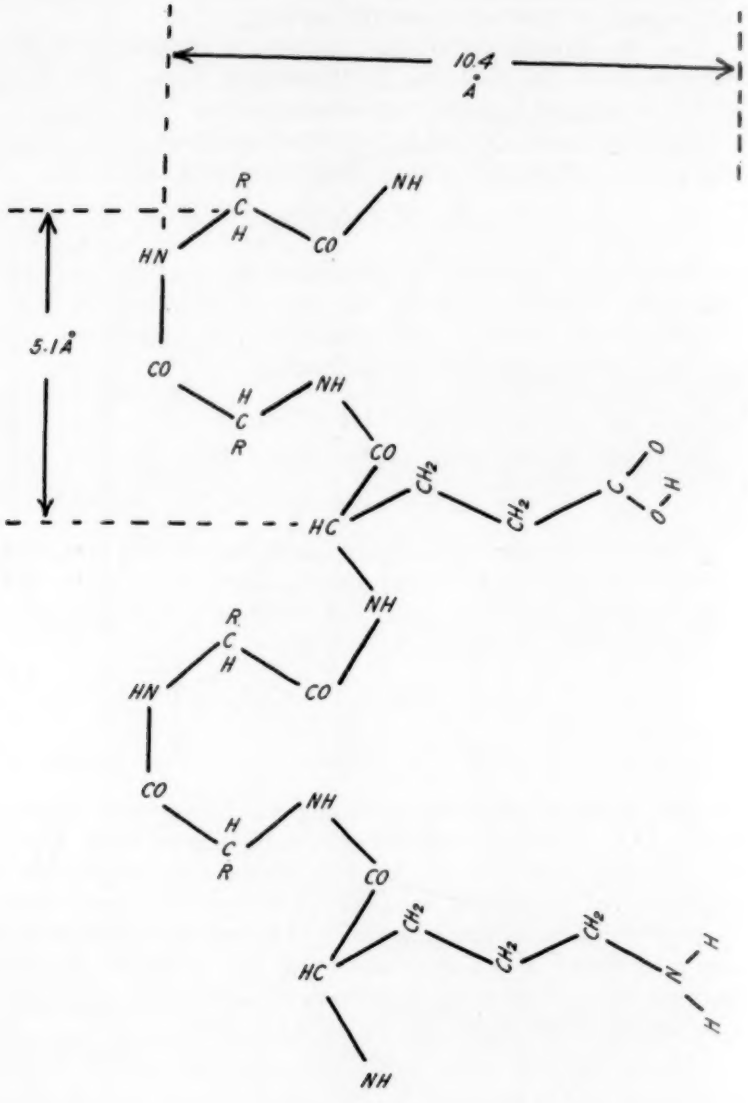
in a polypeptide chain is according to Meyer and Mark [8] about 3.4 Å. Astbury and Woods [9] have shown from X-ray and elasticity data that natural hair fibers in the unstretched state have not the simple zig-zag type of structure but consist of a peptide chain folded in a series of hexagons which have a main periodicity of 5.1 Å. Assuming the α keratin type of structure for a close packed protein monolayer in the "gel" state the structure shown in Fig. 3 is obtained.

The distance of 10.4 Å. between the polypeptide chains

[8] "Der Aufbau der Hochpolymeren Organischen Naturstoffe," Schulze and Co., Grofenhainischen.

[9] *J. Text. Inst.*, **23**, 117 (1932).

FIG. 3.


10.4 Å
5.1 Å
R
C
H
NH
HN
CO
CO
H
C
R
NH
CO
HC
CH2
CH2
C
O
O
H
NH
R
C
H
HN
CO
CO
H
C
R
NH
CO
HC
CH2
CH2
CH2
N
H
H
NH

was obtained by taking the length of a hydrocarbon zig-zag as 2.5 Å. and assuming the length and distance of approach of the polar groups to be 4.5 Å.

From the diagram the area per three amino acid residues is $5.1 \times (3.4 + 2.5 + 4.5) = 53$ Å.^{2}. On compression of the film the side chains will close in with the polar groups remaining in the surface until the distance between the chains is 4.3 Å., the resulting area per hexagonal unit being $5.1 \times (3.4 + 4.3) = 39$ Å.^{2}. The above values agree very well with those found experimentally, for on computing the maximum and minimum areas from the limiting surface concentrations over which the ΔV, C curves were linear we obtain the values 52 and 36 Å.^{2}. As observed, on compression beyond an area of ca. 39 Å.^{2} some of the polar groups would be forced out of the surface with a resulting decrease in the slope of the ΔV, C curve.

SUMMARY.

A quartz fiber microbalance suitable for weighing and spreading of minute quantities of material has been described.

From force-weight characteristics of films of egg albumen, serum albumen, and edestin, it has been shown that a linear compression curve was obtainable over a surface concentration range of 1.43×10^{-7} gms./sq. cm. to 2.40×10^{-7} gms./sq. cm.

Surface potential measurements on the above proteins have shown that homogeneous films were obtained, as indicated by the linear ΔV, C curves, over a surface concentration from 1.31×10^{-7} gms./sq. cm. to 1.93×10^{-7} gms./sq. cm.

In the case of isodisperse proteins having a particle mass greater than 34,500 spontaneous spreading to form a homogeneous film does not occur if the pH of the substrate is within the pH stability range of the protein.

Some experiments have been carried out on the tryptic digestion of casein and albumen films.

The α keratin type of structure has been suggested as the probable form in which the protein micelles exist in a close packed film.

Colorimetric Determination of Hydrocyanic Acid.—NATHAN GALES AND ANDREW J. PENSA (*Ind. and Eng. Chem.*, Analytical Edition, 1933, V, 80–81) recommend the following procedure for the colorimetric determination of small amounts of hydrocyanic acid. The solution is acidified with tartaric acid, and the hydrocyanic acid is removed by distillation. The distillate is collected in decinormal sodium hydroxide solution. The resulting solution is treated with hydrochloric acid in a suitable glass container which is then sealed, and heated in an oil bath at a temperature of 140° to 150° C. for 30 minutes. The hydrocyanic acid is thereby saponified or hydrolyzed, and converted into formic acid and ammonium chloride. The contents of the sealed vessel are allowed to cool, then transferred to a beaker. The excess acid is removed by evaporation almost to dryness. The residue is diluted with distilled water, and its ammonia content is determined colorimetrically after addition of Nessler solution to develop the characteristic yellow color. Since the molecule of hydrocyanic acid and that of ammonia each contains one atom of nitrogen, the hydrocyanic acid content of the sample may then be readily calculated.

J. S. H.

Doing Sixty on Powdered Sugar.—(*Science Service.*) K. CUKER, a persistent Czecho-slovakian chemist, has succeeded in replacing gasoline in part by powdered sugar as an automotive fuel. As sugar refiners know all too well, sugar dust can be a powerful explosive and it is this property Mr. Cuker has sought to put into practical utilization.

Owing to the high cost of liquid motor fuels in Europe, numerous attempts have been made to burn cheap powdered fuels in internal combustion engines; but the ash left by such fuels has been a serious obstacle. Sugar, as an ashless fuel, does not have this objection; the chief technical problem is that of insuring the detonation of this powdered sugar-air mixture in the cylinders of an engine.

Cuker's method for satisfactorily using sugar is to make a composite liquid and solid fuel. Alcohol, denatured with naphthalene, is the liquid vehicle, in the proportion of about 3 parts to 1 of sugar. Detonation is ensured by adding less than 1 per cent. of nitrated sugar, which is more explosive than sugar dust. This mixture, when atomized into an engine cylinder, will explode as certainly and as effectively as gasoline.

SECONDARY EMISSION OF ELECTRONS FROM MOLYBDENUM.

BY

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ABSTRACT.

The ratio of the number of secondary electrons to primary electrons of various energies incident on a molybdenum plate (previously subjected to severe heat treatment) was measured. The results obtained resemble those reported by Petry more closely than they do the more recent work of Hyatt and Smith. Possibilities for explaining discrepancies are suggested.

Molybdenum has been used much in the study of phenomena influenced by surface conditions, since severe heat treatment of the metal is possible. Petry [1] (using apparatus in which the total current was measured as the sum of that to the target and the cylinder surrounding it) determined the ratio of the secondary current to the primary current for energies of the primary electrons up to 1,500 volts. More recently Hyatt and Smith [2] (using a simple three electrode tube in which the electron current was assumed to divide between the grid and plate like positive ion currents for which it had been calibrated) reported results for the secondary emission of electrons due to primary electrons with energies as high as 2,000 volts. Still more recently Soller [3] (using the magnetic deflection method) measured the velocity distribution of the secondary electrons from a very thoroughly outgassed molybdenum plate.

The results of Hyatt and Smith differed considerably from those of Petry. The maximum reported by Hyatt and Smith was somewhat lower than that of Petry and was located at a higher value for the energy of the incident electrons. That contamination of the metal surface used by Petry would be

[1] Petry, *Phys. Rev.*, **28**: 362 (1925).
[2] J. M. Hyatt and H. A. Smith, *Phys. Rev.*, **32**: 929 (1928).
[3] Theodore Soller, *Phys. Rev.*, **36**: 1212 (1930).

adequate to explain both of these effects, is seen at once from the results reported in the preceding paper,* and since Petry used ground joints with an outside seal of DeKhotinsky cement, it was not inconceivable that such contamination might have occurred. It seemed worth while to redetermine the secondary emission of molybdenum by a method resembling that of Petry but in apparatus free from all ground and waxed joints; so that vapors could be eliminated by baking.

DESCRIPTION OF APPARATUS AND EXPERIMENTAL PROCEDURE.

The electrical parts used to measure the secondary emission were described briefly in the preceding paper.* Figure 1 gives the details of the apparatus. The source of electrons is a short tungsten filament mounted in the electron gun at the right. The electron beam is limited by the first of the two diaphragms at *D*. The beam may be allowed to fall on the target, *T*, and the net current measured; or with the target pulled aside, the beam may be allowed to enter *C* where it is absorbed and measured. The metal parts were of molybdenum, and the earth's magnetic field was compensated by two sets of Helmholtz coils.

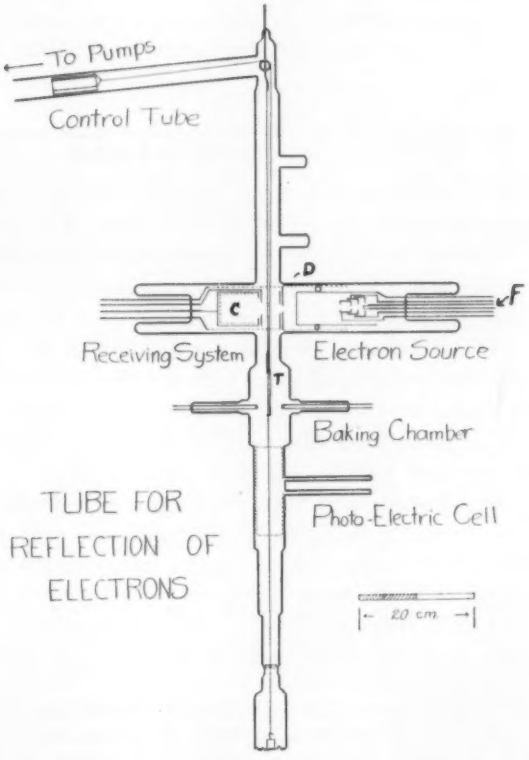
As shown in the figure, the targets are suspended from the top of the apparatus. The two heavy tungsten wires of the seal at the top have a horizontal cross wire between them which supports a pulley. From the bottom of each of these heavy wires a five mil tungsten wire (used for guiding the targets) passes down through loops of wire extending out from opposite sides of the targets. For the sake of spacing, the wires pass through holes drilled in a copper lug into an enlargement where iron weights are attached to keep them taut. The targets are held in place along the vertical guide wires by means of a five mil phosphor-bronze wire which is passed over the pulley at the top and attached to an iron cylinder in the control tube. The targets may then be moved into any position desired by the action of an electromagnet on this cylinder. Any target may be placed opposite the opening of the diaphragms *D*, to intercept the electron beam; or it

* J. F. I., **215**: 435 (1933).

may be lowered into the baking chamber and heated by electron bombardment.

The connection to the pumps is made through the control tube, two liquid air traps in series, and a mercury cut-off. The pump system consisted of a two stage mercury diffusion pump backed by a Cenco Hyvac. Care was taken to get the best obtainable vacuum before observations were made. The

FIG. 1.



system could be sealed from the pumps for several days without the pressure increasing above 10^{-4} mm. Hg; under the best conditions, the gas pressure remained too low to be measurable on the McCleod gauge.

The pumps were run continuously just preceding and during the taking of observations. With the pumps in operation, the entire system up to and including the first trap was baked

for twelve hours at temperatures from 350° to 500° C., the main tube and the upright always being subjected to the higher temperatures. Liquid air was then placed on the trap nearest the pumps and the heating of the entire system including the trap nearest the experimental tube was continued for another half hour. The heating of the trap was then discontinued; it was cooled and immersed in liquid air as soon as possible. The heating of the rest of the tube was then stopped and liquid air was maintained on the traps until desired readings were completed. Under operating conditions the pressures in the tube were always below that observable on a McCleod gauge.

SECONDARY EMISSION OF ELECTRONS FROM CLEAN MOLYBDENUM—A COMPARISON AND DISCUSSION OF RESULTS.

After the preliminary baking of the tube as a whole, the target was baked for an hour at red heat, and for shorter intervals of time at higher temperatures (near the melting point of platinum). After each such treatment, the secondary emission was measured [4] for various energies of the incident electrons. In the course of this conditioning, the secondary emission varied considerably. The results obtained at the end of the heat treatment are shown by the open circles in Fig. 2. For comparison the results of Petry (curve 1) and those of Hyatt and Smith (curve 2) are included.

The results obtained in this work are very similar to those obtained by Petry. A definite discrepancy can hardly be said to exist, since in the course of the heat treatment curves were obtained which were identical (within experimental error) to the one due to Petry. Also differences in apparatus [5] might lead to observations differing by the amount

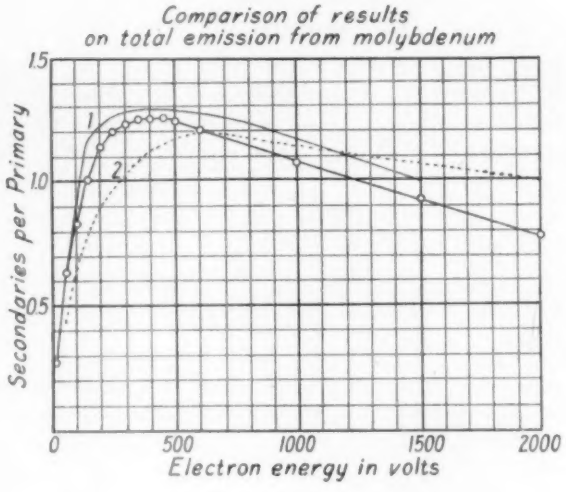
[4] Since preliminary experiments had indicated that the secondary current from a clean metal (in the present apparatus) was nearly saturated when the surroundings of the target were made positive by one tenth of the potential difference between the target and the filament, this was the condition under which the secondary emission was measured.

[5] Petry mentions the possibility of losing electrons by reflection back through the aperture of his diaphragm by virtue of which he might underestimate his primary current by as much as 2% (and hence increase his ratio above the true value by something of the same order. The same source of error in the present apparatus was estimated geometrically to be about 0.01% and hence very probably negligible.

shown even though the secondary emission was actually the same.

The disagreement with the results of Hyatt and Smith is more marked. Curves 2 and 3 not only depart very appreciably from one another, but they differ in details (such as position of the maximum and slopes) for which curves 1 and 3 agree within experimental error. The preceding paper indicates that these latter characteristics are fairly stable throughout the final stages of the heat treatment; so the

FIG. 2.



difference is probably not due to differences in surface conditions. It appears, then, that curves 1 and 3 differ because of significant differences in the method of measurement.

It is difficult to see how the secondary emission of electrons could be measured accurately in the simple three electrode vacuum tube of Hyatt and Smith. Even assuming that the primary current divides between the grid and plate as assumed, other electrons of unknown velocity might be incident on the plate in considerable numbers. Some of the electrons incident on the grid would be expected to reach the plate by reflection, and a considerable number of the electrons striking

the target would be reflected to another part of the target [6] rather than going to the grid. These two processes might give rise to a considerable number of electrons striking the target with only a fraction of the primary energy, and this appears adequate to explain both the slight lowering of the maximum and the shift of all points on curve 2 (including the maximum) to higher primary energies.

CONCLUSION.

In view of the difficulty of getting consistent results in a measurement influenced by surface conditions, the agreement between Petry's results and those obtained in this study is quite satisfactory. The geometry of the two sets of apparatus and the methods of measurement differed enough to make the check interesting, and the agreement in the shape of the curves may be taken as evidence that the properties of molybdenum which determine the shape of the curves are fairly stable.

The writer wishes to thank the members of the staff of The Department of Physics of the State University of Iowa for their interest and assistance. Thanks are especially due to Professor J. A. Eldridge, who suggested and directed the investigation.

[6] This effect would be increased by the cylindrical form of the target and by the reduced effective area of the grid exposed to a reflected electron.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RADIO SYSTEM FOR BLIND LANDING OF AIRCRAFT.

Practical tests of the radio system for the blind landing of aircraft, developed by the Bureau of Standards for the Aeronautics Branch of the Department of Commerce, are being carried on at the Newark Municipal Airport, Newark, N. J. In some of these tests the pilot lands the airplane while sitting in a hooded cockpit, so that nothing outside is visible. Other tests are being made in foggy weather, a condition which is generally not as severe as the artificial one first mentioned. The equipment at Newark is available for use by any airplane having the necessary receiving apparatus.

The present system was developed as the result of several years of research work, which may be divided roughly into three stages: Fundamental experiments to develop the component parts of the system; practical development of these component parts, and demonstration of their practicability in tests at the bureau's experimental flying field, College Park, Md.; and the present tests of the complete system at a commercial airport.

The system, as illustrated by the installation at Newark includes three elements: A runway localizing beacon; a set of two marker beacons; and a landing beam. These three elements give the airplane its position in three dimensions while landing. The runway localizing beacon operates on 300 kilocycles and is similar to the visual-type transmitters designed by the bureau for radio range-beacons of the Federal airways. Small crossed-loop antennas are employed, so that the beacon does not constitute an obstruction to flying, and a goniometer allows the course to be swung over an arc of 40°. This covers the northeast quadrant from which winds are usually blowing at Newark during foggy weather. The marker beacons operate at 10,000 kilocycles. One is placed about 2,000 feet beyond the edge of the landing area while

* Communicated by the Director.

the other marks the edge of the field. These are low-power transmitting sets with long, low, horizontal antennas. They operate from the commercial power supply, and different modulation frequencies make it easy to identify the two beacons. The landing-beam transmitter employs an ultra-high frequency (100,000 kilocycles). The antenna array consists of 12 half-wave horizontal antennas, so grouped as to give the necessary directivity of beam in the vertical plane, while spreading the beam out horizontally to cover the 40° sector. This results in a fan-shaped beam which provides vertical guidance for all orientations of the runway beacon course, within the limits specified. In using the landing beam the pilot follows a course of equal signal intensity, below the axis of the beam, this path being a curve tangent to the ground, thus giving proper conditions for landing.

The receiving equipment on the airplane consists of: The regular medium-frequency receiving set commonly used by air transport operators, augmented by a reed converter and automatic volume control, for picking up the signals of the runway localizing beacon; a marker-beacon receiving set operating on 10,000 kilocycles and giving aural signals in headphones; and a landing-beam receiving set employing a detector tube, audio-frequency amplifying tube, reed filter, and cuprous oxide rectifier, and operating at 100,000 kilocycles.

The reed converter of the medium-frequency receiving set and the landing-beam receiving set are connected to the vertical and horizontal pointers, respectively, of a combination indicating instrument mounted on the instrument board of the airplane. The vertical pointer shows whether the plane is on or off the course in the horizontal plane, while the horizontal pointer shows whether it is on, above, or below the vertical course marked out by the landing beam. A control panel is provided for controlling the receiving sets, for reversing the vertical pointer to take care of flights toward and away from the beacon, and for adjusting the steepness of the landing path to suit the plane. A switch permits connecting the horizontal pointer to the output of the reed converter to test out the receiving set, or to the landing beam and marker beacon receiving sets.

The method of landing is similar to that ordinarily followed, except that the pilot, instead of watching the horizon and the ground, watches the two pointers of the combination indicator and listens to the signals of the marker beacons.

The experiments at Newark cover the determination of the most suitable radio frequency (from the point of view of the airline operator) for the marker beacons, including the possibility of using the same radio frequency for marker and runway beacons. This would eliminate the necessity for the separate marker beacon receiving set. Careful adjustment of the marker-beacon power output would be necessary to prevent interference. In other tests the markers will be operated on frequencies in the aircraft communication band (3,000 to 6,000 kilocycles), so that the high-frequency radio receiving sets usually carried on aircraft may be utilized. Control equipment to enable the pilot to switch from marker signals to communication and vice versa with minimum effort, has already been provided.

During the past month many pilots, airline operating officials, and others have tried the system under operating conditions at the Newark Airport. They have commented unanimously upon its excellent practicability and convenience.

BRUSH DISCHARGE IN AIR AFFECTS ENGINE PERFORMANCE.

Tests have recently been undertaken which indicate that electrical excitation of the atmosphere has a measurable effect on automotive engine performance. In this work a potential was maintained between two electrodes at the carburetor entrance. As the potential was increased, a measurable change of power was noted, as well as an increasing effect on detonation. The amount of the effect on detonation varies not only with the potential, but also with the polarity of the grounded electrode and with the fuel used. While definite conclusions cannot be drawn as yet it is possibly significant that the ionization produced by 15 milli-curies of radon had no effect on detonation, and that the ozone concentration in two cases was roughly proportional to the effect on detonation.

EARTHQUAKE ACCELEROMETERS.

The recent earthquake in California afforded a test of three accelerometers designed by Dr. F. Wenner of the Bureau of Standards for the Coast and Geodetic Survey. One of these instruments was located at Long Beach and two at Los Angeles. All three instruments gave satisfactory records. As the periods of the accelerometers were 0.1 second, the records represent approximately the accelerations of the ground in cases in which these accelerations continued for a sufficient time to cause forces destructive to buildings. The destructive accelerations in a horizontal direction were approximately 0.1 gravity, while maximum horizontal accelerations, but of very short duration, were probably equal to gravity. It is probable that these records are the first made in this country from which data of interest to structural engineers may be obtained.

EFFECT OF ALTITUDE ON THE LIMITS OF SAFE OPERATION OF GAS APPLIANCES.

A study of several types of domestic gas appliances operating at high altitudes was recently completed by the bureau's gas chemistry section. In order to determine what changes in appliances might be necessary to safeguard the public who use such appliances in cities several thousand feet above sea level, the observations were made in a small chamber built of heavy reinforced concrete. After testing an appliance with the door of the chamber open (approximately sea level) the door was closed and the air pumped out until the pressure within was lowered to the same barometric pressure as exists at such a place as Denver, Colorado, which is one mile high. The appliance was again put through the same series of tests, keeping all the conditions exactly the same, except the barometric pressure. Tests were made at pressures corresponding to altitudes as high as 11,000 feet.

Many of the facts which were brought to light had scarcely been suspected until a few months before the work was started. Appliances which were found to be in excellent condition when tested at the laboratory of the American Gas Association in Cleveland had been found to produce dangerous

quantities of carbon monoxide when tested in Denver. If the high altitude was the cause of the failure of the standard tests to insure safety to the user, what could be done to make these appliances as safe in Denver as they already were in Cleveland?

A coöperative research by the Bureau of Standards and the American Gas Association was therefore undertaken, and the results were presented in a paper read before the 85th meeting of the American Chemical Society in Washington by Dr. Francis A. Smith. In this report the effects of high altitude on gas appliances, the reasons why these effects are produced, and some remedies were discussed in detail.

Appliances depend on natural draft for their supply of air and the elimination of products of combustion. With a given appliance, it was found that the combustion of the maximum amount of gas that could be completely burned resulted in the production of substantially the same volume of gaseous products of combustion and the flow of the same volume of air, whatever the altitude.

Gases expand when the pressure is reduced—when the altitude is increased. Because of this expansion, fewer heat units will be contained in the gas which fills a given volume. Since the volume is limited, it follows that heat must be produced at a lower rate at a high altitude if carbon monoxide is to be avoided.

A mental picture of what happens in a given appliance may be had by considering the products of combustion as occupying an increasing proportion of the total capacity of the flue passages as the gas rate is increased, while the amount of air which enters the appliance does not increase in proportion and finally becomes insufficient to complete the combustion of the gas.

As soon as the altitude starts to increase the number of heat units that can be liberated per hour without incomplete combustion starts to decrease at the rate of about 4 per cent. for every thousand feet of altitude, until, to avoid this hazard in Denver, heat must be produced at only about 80 per cent. of the highest rate which is possible at sea level. This effect was found to be nearly the same for several very different types of appliances, except radiant heaters. The

maximum safe rate for these heaters at the altitude of Denver is only about 70 per cent. of that at sea level.

If it is desired to produce heat safely at the same rate at a high altitude as at sea level, larger passages for the escape of the larger quantities of flue gases must be provided.

The effect of changing altitude on the useful work which a given quantity of heat will perform (efficiency) was found to be insignificant in the case of a top burner of a range with grid top.

Yellow flame pilot lights were found to be unaffected by increasing the altitude except where they were surrounded and "smothered" by flue gases from the main burner which could not escape fast enough through the flue.

At high altitudes a larger volume of gas is required to supply a given number of heat units. The mixture of gas and air which flows from the holes of the burner therefore emerges at a higher velocity. The flames are consequently more easily blown away from the burner at high altitudes than at sea level.

Further tests, in which propane (Pyrofax, Philgas) was burned, indicated that these effects of altitude would be the same for any of the fuel gases distributed.

BURNERS FOR SLOW-BURNING GASES.

The bureau recently completed two blast burners for slow-burning gases, and so far these have shown satisfactory characteristics. With these burners it is easy to work pyrex with propane without the aid of oxygen, and reasonably easy to work quartz in a quiet flame when using oxygen and propane. Progress is being made on the design of burners of the Tirrill and Meker types for use with slow-burning gases.

ABSOLUTE DETERMINATION OF THE AMPERE.

The value of the ampere has been determined in absolute units at the bureau, using a current balance, in which the force between coils carrying a current is measured. The current balance originally used by Rosa, Dorsey, and Miller was employed, but the apparatus has been modified in many important respects.

Four sets of coils were used. The important constant in the computation of the current from the force between the coils is the ratio of their radii. Eight experimental determinations of these ratios have been made giving results which are self-checking and which show no errors larger than ± 6 parts in a million. Four series of determinations of the force give results in which the average deviation from the mean is about ± 3 parts in one hundred thousand. The results may be expressed as

1 Bureau of Standards International Ampere
= 0.99994 Absolute Ampere.

A report of this work will be made at the meeting of the American Physical Society in Washington, April 27–28, and will be published later in the *Bureau of Standards Journal of Research.*

ABSOLUTE DETERMINATION OF THE OHM.

A determination of the ohm in terms of the units of length and time has been made at the bureau. The method depends on the measurement of a self inductance in terms of time and the present unit of resistance, and on the computation of the inductance from measurements of the dimensions of the inductor.

Three single layer solenoids were measured. They were constructed with such care that the inductance can be computed from the measured dimensions with an error of only a few parts in a million. The measured inductance can be measured in terms of resistance and time with about the same accuracy. The result is expressed as

1 Bureau of Standards International Ohm
= 1.00045_2 Absolute Ohms.

This result will be presented at the meeting of the American Physical Society, April 27–28.

STANDARDIZATION OF PAPER TESTING METHODS.

Further progress in development of paper testing standards by the Technical Association of the Pulp and Paper Industry,

was reported at the annual association meeting, February 13, by B. W. Scribner, Bureau of Standards, chairman of the association's paper testing committee.

Tentative methods for alpha cellulose, copper number, total acidity, ink absorption of blotting paper, absorption of water by bibulous papers such as toweling, and water resistance were completed by the committee during the past year. The methods for alpha cellulose and copper number, used as measures of chemical purity of cellulose, are based on well-known procedures for pulp, with modifications by Burton and Rasch to adapt them to paper. Total acidity is determined essentially according to the Kohler-Hall method. The distinctive feature of this method is three successive aqueous extractions of finely-ground test specimens to obtain the acid for titration. The methods for absorption of ink and of water are similar; a measured quantity of the liquid is delivered on the surface of the paper, and the time for complete absorption, as indicated by no further reflection of light from the liquid, is noted. Reed's method for ink absorption of blotting paper was used as the basis of these methods. The water-resistance method is based on the dry-indicator method developed by Carson. In this method the permeation of water is measured by finding the time required for change in the color of a sugar-dye mixture on the upper surface of test specimens floated on water.

In most cases, the details of these methods are developed through joint laboratory testing by members of sub-committees. Considerable work of this kind is in progress for development of new methods or improvement of existing methods. Further study is being made of means of measuring water resistance and grease resistance. A sub-committee on chemical methods is studying determination of pH, active sulphur, iron, and resin. Another sub-committee through coöperative testing is finding whether or not improved accuracy in fiber analysis of paper can be obtained by "weight factors" for fibers to take into account the differences in specific gravity of fibers. In making paper, fibers are mixed by weight, but in testing paper their relative proportion is estimated by volume. The association methods for strength and other physical properties are being revised by a sub-

committee recently formed for the purpose. This work is of particular interest, as it is being done on an international scale through the coöperation of several foreign organizations interested in paper testing standards. The testing of paper, because of its heterogeneous nature, is not simple, but these coöperative studies of the problems involved are leading to ultimate solution of them.

FACTORS FOR EXPANSIVITY OF GROUND COAT ENAMELS.

Some results of this study were given in Technical News Bulletin No. 184 (August, 1932), but no factors had been derived from the data at that time. Since then a group of factors have been worked out which fit the enamels under investigation better than the factors to be found in the literature. Such an improvement is not surprising, since the other factors were not derived expressly for use on typical ground coat sheet iron enamels, as in this case. Nevertheless, the factors of Winklemann and Schott, of Mayer and Havas, and of Hall gave good approximations when used with a proper regard for the temperature ranges within which they were obtained.

The following factors, although they may be subject to revision, especially in the case of K_2O and Al_2O_3, were found to give satisfactory results for the type of enamel under study. The constituents included comprise about 90 per cent. of the enamel batch, and for the remaining 10 per cent. the factors of Mayer and Havas are to be used.

Constituent.	*Factor.*
Na_2O	9.0
B_2O_3	1.0
SiO_2	1.1
Al_2O_3	3.3
K_2O	7.6

When these factors are multiplied by the percentages of the respective constituents, and the products are added, there is obtained a value which, when multiplied by 10^{-7}, gives the coefficient of cubical thermal expansion from 20 to 100° C. To obtain mean coefficients to 200°, 300°, and 400° C., the results should be multiplied by 1.04, 1.09, and 1.15, respectively.

HIGH EARLY STRENGTH CEMENTS.

A study of the properties of the high early strength cements is nearing completion. For this study 12 different brands were obtained, from different sections of the country. Six by twelve inch concrete cylinders were made, using a 1 : 2 : 4 mix, with three different water-cement ratios, viz., 6.5, 7.5, and 8.5 gallons per sack of cement. Cylinders were made for each of four initial conditions, i.e., the first 24 hours after making, thus:

1. Materials at 70° F., cylinders stored in air at 70° F.
2. Materials at 90° F., cylinders stored in air at 90° F.
3. Materials at 110° F., cylinders stored in air at 110° F.
4. Materials at 70° F., cylinders stored in an insulated box.

Subsequent storage, after the first 24 hours, was of four types: (1) Air at 70° F.; (2) Damp room at 70° F.; (3) Outside; (4) Freezing and thawing.

Volume changes were obtained by measuring the length of the cylinders with a dial micrometer.

Some of the results thus far obtained are given in the table:

Compressive Strength at 1 Day, 28 Days, and 1 Year.
6.5 Gal. Per Sack, Damp Storage.

Initial Condition, ° F.	Highest. lbs./in.²	Lowest. lbs./in.²	Average. lbs./in.²
1 Day.			
70	1,520	900	1,190
90	2,430	1,520	1,980
110	2,680	1,330	2,090
Insulated box	2,380	1,310	1,760
28 Days.			
70	5,560	3,690	4,610
90	5,300	3,100	4,270
110	4,980	2,350	3,480
Insulated box	4,240	2,930	3,690
1 Year.			
70	6,410	3,880	5,520
90	6,240	3,650	5,310
110	5,520	3,070	4,280
Insulated box	5,180	3,500	4,520

The 7.5 and 8.5 gallon per sack mixes (70° initial) gave one-day strengths averaging 815 to 510 lbs. per sq. in., respectively. These are 31.5 and 57.2 per cent. lower than the corresponding average (1,190) for the 6.5 gallon mix.

THE FRANKLIN INSTITUTE.

(PROCEEDINGS OF THE STATED MEETING HELD WEDNESDAY, APRIL 19, 1933.)

The regular monthly meeting of The Franklin Institute was called to order at eight-fifteen P.M. by the President, Mr. Hayward.

He announced that there was no business to be transacted but that a few notices would be read by the Secretary.

The Secretary announced that on Wednesday, May third, in the latter part of the afternoon, a special meeting would be held in honor of Dr. Niels Bohr of Copenhagen, Denmark, the initiator of theories of atomic structure. Dr. Bohr was the recipient of a Franklin Medal some years ago but has not had an opportunity to attend a meeting of The Franklin Institute before this time. It is hoped that the physicists of this section of the country and members of the Institute will give a hearty welcome to Dr. Bohr. Full information will be sent out at an early date.

He further called the attention of the membership to the annual Medal Day exercises which will be held at three-thirty P.M. on Wednesday, May seventeenth. He stated that a distinguished group of scientists and industrialists would be awarded medals this year, and named especially the following: Mr. Igor I. Sikorsky, inventor of the multimotored airplane of various types as the recipient of a Potts Medal; Senor Juan de la Cierva, inventor and developer of the autogiro, as the recipient of the Cresson Medal; and Dr. Orville Wright of Dayton, Ohio, the great initiator of human flight, as the recipient of the Franklin Medal. In addition to the latter, Dr. Paul Sabatier, Dean of the Faculty of Science of Toulouse University, France, a chemist of international reputation, the discoverer of the catalytic property of many common metals, and a Nobel Prize medalist, would be awarded the second Franklin Medal.

The Secretary further made an announcement concerning the satisfactory progress which has been made in the building operations on the Parkway, and the definite promise of the builders that the building could be opened for the activities of the Institute on or before December 1, 1933.

The President then presented the lecturer of the evening, Dr. W. F. G. Swann, Director of the Bartol Research Laboratories of The Franklin Institute. Dr. Swann spoke eloquently and most interestingly on some fundamental researches which are being carried on at the Bartol Laboratory. His lecture was illustrated by a wealth of brilliant experiments, showing delightfully the work which has been carried on.

The talk was followed by some discussion, after which the meeting adjourned at nine-fifty-three. Many members of the audience remained, investigating the apparatus shown and asking questions, until nearly eleven o'clock.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, April 12, 1933.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 12, 1933.

MR. T. F. CLARK *in the Chair.*

The following reports were presented for Final Action:

No. 2961: Photo-Flash Lamp.

This report recommended the award of the John Price Wetherill Medal to Mr. Johannes B. Ostermeier, of Mering bei Augsburg, Germany, "In consideration of the very careful and scientific development of all the factors involved in the production of a dust-free flash lamp, utilizing the combustion of aluminum foil in an atmosphere of oxygen in a closed glass bulb, whereby an intensely luminous flash of short duration is obtained in a safe and convenient manner."

No. 2969: New Methods in Astronomical Photography.

This report recommended the award of the John Price Wetherill Medal to Messrs. Henry S. Hulbert, Francis C. and Robert R. McMath, of Detroit, Michigan, "In consideration of their design and construction of novel apparatus for the making of motion pictures of astronomical subjects, which have proven of value in the teaching and popularization of astronomy."

The following reports were presented for first reading:

No. 2912: Self-Locking Bolt and Nut.

No. 2959: Automatic Cab Signal System.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, April 19, 1933.)

RESIDENT.

MR. ROBERT L. BOYER, Engineering Aide, Frankford Arsenal, Philadelphia, Pa. For mailing: 6040 Webster Street, Philadelphia, Pa.

MR. CHARLES M. BURRILL, Radio Engineer, RCA Victor Company, Inc., Camden, N. J. For mailing: 162 Windsor Avenue, Haddonfield, N. J.

MR. ALVIN V. GRUBER, Ceramist, Metals Coating Company of America, 495 North Third Street, Philadelphia, Pa. For mailing: 1117 Magnolia Avenue, Camden, N. J.

MR. GEORGE F. OTTO, Technician, Chemical Laboratory, Philadelphia Electric Company, 2301 Market Street, Philadelphia, Pa. For mailing: 3357 Ainslie Street, East Falls, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. DONALD C. A. BUTTS, 112 West Winona Avenue, Norwood, Pa.

MR. HARRY F. FLYNN, 200 Kenmore Road, Brookline, Upper Darby, Pa.

MR. CHARLES F. FORSTALL, c/o Reading Company, Room 309 Reading Terminal, Philadelphia, Pa.
MR. EDWIN D. A. FRANK, 2752 North Summit Avenue, Milwaukee, Wis.
MR. PENROSE R. HOOPES, 1019 West Farragut Terrace, West Philadelphia, Pa.
MR. ERNEST JOHANSEN, 4530 Osage Avenue, Philadelphia, Pa.
MR. ARTHUR F. POOLE, 305 Parkway, Ithaca, N. Y.
MR. BENJAMIN E. SHACKELFORD, RCA Radiotron Company, Inc., 415 South Fifth Street, Harrison, N. J.
MR. FRANCIS B. VOGDES, 608 New Street, Plainfield, N. J.

NECROLOGY.

Brigadier General James Allen, Washington, D. C.
Commander Albert C. Dieffenbach, Germantown, Philadelphia, Pa.

LIBRARY NOTES.

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ZIEGELMAYER, WILHELM. Unsere Lebensmittel und ihre Veränderungen. Mit einer Darstellung der Lehre von der Kochwissenschaft. 1933.

BOOK REVIEWS.

MICROENERGETIQUE, Tome I, Introduction, par Pierre Bricout. Preface de M. Ch. Fabry, Membre de l'Institute. vi–303 pages, 16 × 25 cms., paper. Paris, Gauthier-Villars et Cie, 1933.

Under the title "Ondes et Electrons," Professor Bricout in 1929 published a concise outline of atomic physics (Collection Armand Colin No. 113) to meet the requirements of general readers in physical science or to serve as an abridged survey for those intending to proceed further to a detailed study of the subject. The rapid exhaustion of two editions of that work is ample testimony to the author's success in presenting a connected and lucid exposition of a subject whose formidable mathematical background excluded many readers.

Having thus provided an account within the reach of those who are not trained in abstruse analytical methods, Professor Bricout now proceeds to an exhaustive examination, limited to the properties of the atom and the molecule, in the progress of which the abundant store of mathematical processes of analysis are employed without stint. Wisely, the author does not leave to the reader the task of picking out from original sources these mathematical devices, but provides in an extensive introduction, which occupies about one-half the volume, a collection of the mathematical theorems which are employed in developing the energy relationships which prevail within the boundaries of atomic structure, descriptively named "Microenergetique." The entire volume is devoted to this mathematical and physical groundwork.

Reserved for a second volume, the third part continues the subject with an exposition of the classic quantum theory and wave and quantum mechanics, and the examination of the principal atomic phenomena and their comparison of computed with experimental results.

The treatise is a deductive text in which are collected the analytical and experimental data needed for systematic and successful perusal of the subject.

L. E. P.

LA TRANSFORMATION DE L'ÉNERGIE ÉLECTRIQUE. II—COMMUTATRICES ET REDRESSEURS. Par Henri Giroz, Ingenieur E. S. E., Preface par M. P. Janet, Membre de l'Institut (Collection Armand-Colin No. 131). vi–218 pages, paper, illustrations. Paris, Librairie Armand Colin, 1932. Price 10 francs 50.

The subject of the universally used static electric transformer was treated in no. 78 of this series. The present volume deals with motor-generators, the electric converter, and the mercury-arc rectifier. The last-named may be truly termed the first industrial product of the electronic principle.

Along with a theoretical examination which is at once condensed and satisfying, the author has gathered a collection of practical data of value alike to designers and commercial engineers which is as complete as the volume of the work permits. Of especial note are the diagrams and tables from which may be quickly obtained the theoretical constants of the principal connections which are employed in the primary circuits of rectifiers.

The work is informative and concise and should prove an excellent reference manual as well as a text for systematic reading.

L. E. P.

CHEMICAL ANALYSIS BY X-RAYS AND ITS APPLICATIONS, by Georg von Hevesy, Professor of Physical Chemistry, University of Freiberg. 333 pages, figures, tables, 15.5 × 23.5 cms. New York, McGraw-Hill Book Company, Inc., 1932. Price $3.00.

This volume is the tenth of those that represent in printed form the series of lectures given under the George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University. The subject of Chemical Analysis by X-Rays is particularly timely since it makes possible the detection and quantitative determination of elements present in very minute amounts. The method of analysis by x-rays is not simple by any means and there are few chemists in the world today who possess a broad knowledge and even broader experience in such exacting and discriminating work.

For successful chemical analysis by means of Roentgen rays a knowledge of x-ray spectroscopy is essential. This is an all-absorbing subject in itself and the author has wisely discarded all that irrelevant to his subject and includes those problems and methods of x-ray spectroscopy only in so far as they affect the work of the x-ray analyst. This subject comprises Part I of the volume. The presentation commences with an introductory chapter on the origin of x-ray spectroscopy and is followed by an account of Moseley's work and development of his fundamental law governing x-ray spectra. A description of the type of apparatus used in x-ray analysis will furnish the reader valuable information regarding the more recent improvements in this field. Following a discussion on emission lines, absorption edges, intensity measurements and relationships, the actual quantitative analysis by x-rays is described and illustrated in considerable detail with the data on the analysis of Thucolite, a primary carbon mineral containing many rare elements. Attention is also given to methods of x-ray analysis by means of secondary radiation including a discussion of disturbing effects and their avoidance. The last chapter of this section contains a critical appraisement of the relative value of x-ray analytical methods. The appendix to Part I firmly

establishes the practical utility of the book. Here will be found the principal x-ray spectral lines of the elements, arranged in order of increasing wave-lengths from 108 to 24,200; list of absorption edges, K, L, M, arranged by increasing wave-lengths, from 107–5 to 9511 XU; the more important comparison lines; disturbing elements; reflection angles and wave-lengths.

Part II contains the extremely interesting story of the discovery and properties of hafnium. The topics taken in order deal with the discovery of hafnium and its separation from zirconium; the properties of hafnium and its compounds; analytical chemistry and occurrence of hafnium; and, the spectrum of hafnium.

Part III deals with the chemical composition of the earth and the cosmic abundance of the elements. Recorded analyses of many meteorites are considered and their significance as true examples of the composition of other stellar bodies is discussed. There is also the remarkable observation that apart from hydrogen, helium and other noble gases, the relative abundance of the elements in the three systems—solar, stellar, and terrestrial—is not very divergent.

Taken in its entirety, this book represents a happy combination of detailed information and data of highly technical nature intended to aid the x-ray analytical chemist and, a more general discourse upon the applications of and conclusions that may be drawn from such analyses in attempts to throw further light upon the constitution and origin of the universe. Such discourses have great popular appeal and echo the tenor of the book's introductory lecture on the Age of the Earth.

T. K. CLEVELAND.

LIFE'S PLACE IN THE COSMOS, by Hiram Percy Maxim. 177 pages, 36 illustrations, 15 × 21.5 cms. New York, D. Appleton and Co., 1933. Price $2.50.

When an eminent technical man indulges in speculations in a field outside that in which he has made his reputation, he is often able to employ a detached viewpoint which makes his opinions a real contribution. But when his account is marred by frequent errors of fact, which betray his lack of knowledge in that field, one is compelled to accept his opinions at a considerable discount.

These observations are inspired by the book under review, which is so good in parts that one wishes the author had made a more careful study of elementary astronomy before writing it, or, at least, that he had permitted his manuscript to be checked by a competent authority.

Starting with a summary of the Solar System and its members, he proceeds to the other bodies in our own Galaxy, and thence to other Galaxies. Then he discusses Life, and the characteristics of living things, the birth of the Solar System, evolution, and intelligence. In a final chapter, entitled "Conclusions," he takes up "Life's cosmic possibilities," the possibilities of interstellar communication, the probable fate of inanimate matter, and "Ourselves."

The opinions expressed in the latter parts of the book are interesting and stimulating. It is in the astronomical summary, that prefaces these conclusions, that most of the errors are found. For instance, when he states, on page 20, that, if the lunar craters were "meteor scars, some of them certainly would show evidence of at least a few meteors having come in at an angle," he completely

ignores the important studies made of bomb craters by H. E. Ives and reported in the *Astrophysical Journal* some years ago. It is not true, as stated on page 42, that "The Pole Copernicus about 1550 got himself into difficulties by pointing out that there were the best of reasons for believing that the Earth and all the planets revolved around the Sun." Copernicus died in 1543, as his book, "De Revolutionibus," was published, and never appreciated the furor which it aroused. The story of Galileo's recantation, under pressure of the Inquisition, is so well known, that it is surprising to read, on page 43, that "pressure was brought . . . to induce him to recant, but he would not." Neither did Galileo "invent" the telescope, as stated on page 52.

Neptune was first observed knowingly by Galle, not "Gerre" (page 46). The north star, Polaris, is not a "fixed point" in the sky, as stated on page 66, nor are stellar positions measured from it. One of the two coördinates used in determining the position of a celestial body, declination, is measured indirectly from the north celestial pole, which is a very appreciable distance from the pole star. "An ordinary clock," does not tell "Sun time," as we read on page 67. On page 74 the author remarks that the Andromeda nebula is "too far away for us Earthians yet to resolve into individual stars." It is well known, of course, that E. P. Hubble did this very thing at Mt. Wilson in 1924, and, in fact, Mr. Maxim reproduces some of his photographs, and describes them on a later page. It is not true, as he declares on page 80, that the funds for the 200 inch telescope now projected for the California Institute of Technology have been provided by the Carnegie Institution, and are in excess of $10,000,000. The International Education Board is the donor, and though no amount has been publicly announced, the figure is very much less than the amount mentioned.

Despite such errors as these, the book is an interesting one, and when he expresses the belief that radio communication with Mars is entirely possible, he speaks in a field of which he has personal knowledge. He also concludes that intelligent life probably exists on Mars, though it is probably vastly different from anything known on Earth, and that life exists in countless worlds in every Galaxy. It is to be hoped that if and when a new edition is required, the errors will be corrected. A good index facilitates reference to the various parts of the book.

JAMES STOKLEY.

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Qualitative Chemical Analysis, by Roy K. McAlpine, and Byron A. Woule, 696 pages, tables, 15.5 × 23.5 cms., New York, D. Van Nostrand Co., Inc., 1933. Price $4.50.

Life's Place in the Cosmos, by Hiram Percy Maxim, 176 pages, plates, 14 × 21 cms., New York, D. Appleton & Company, 1933. Price $2.50.

Experimental Atomic Physics, by G. P. Harnwell, and J. J. Livingood, 472 pages, tables, illustrations, 15 × 23 cms. New York, McGraw-Hill Book Co., Inc., 1933. Price $5.00.

High-Frequency Measurements, by August Hund, 491 pages, tables, illustrations, 15 × 23 cms. New York, McGraw-Hill Book Co., Inc., 1933. Price $5.00.

Societe de Chimie Industrielle Hommage a Henri Moissan, 91 pages, port., 23 × 28.5 cms. Paris, Chimie et Industrie, 1932.

Microenergetique, Tome II, Les Theories et les Faits, 427 pages, 16.5 × 25 cms., Paris, Gauthier-Villars, 1933.

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Les Colloides Manuel de Chimie Colloidale, par H.-R. Kruyt, traduit d'Apres l'Edition Anglaise par J. du Plessis de Grenedan. 329 pages, tables, illustrations, 16 × 23.5 cms. Paris, Librairie Felix Alcan, 1933.

Sammelheft Baustoffe, Bauformen und Betriebsfuhrung der Glasschmelzwannen, 116 pages, illustrations, tables, 21 × 29.5 cms. *Abhitzekessel in Glashutten*, 2. neubearbeitete Auflage, 30 pages, figures, 21 × 29.5 cms. *Sammelheft Baustoffe, Bauformen und Betriebsfuhrung der Glasschmelzofen*, 88 pages, illustrations, plates, tables, 21 × 29.5 cms. Frankfurt a.m., Warmetechnischen Beratungsstelle der deutschen Glasindustrie, 1931.

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CURRENT TOPICS.

A Sodium Lamp.—(*Chem. & Ind.*, **52**, p. 170.) An English firm has developed a simple form of lamp for laboratory use in which a glow discharge takes place in sodium vapor. The principal radiation is from the yellow sodium doublet. All the other radiations together have less than 1 per cent. of the strength of the yellow sodium lines. The lamp is meant to be operated upon a 220 v. A. C. line through the medium of a rectifier which supplies suitable heating current to the filament and also the necessary voltage for the glow discharge. The lamp is started by merely closing the primary circuit of the rectifier and reaches full brightness in about 10 minutes after switching on. A Dewar flask placed over the lamp ensures an even, steady working temperature.

New and Improved Optical Instruments.—(*Chem. & Ind.*, **52**, Sup.8.) At that period of the year bridging February and March there was held in London a British Industries Fair. One of the most interesting exhibits was sponsored by the British Optical Instrument Manufacturer's Association. As might be expected the latest improved types of thermometer, photometer, analytical balance and tintometer all were present.

One remarkable instrument on exhibit was a Vickers Projection Microscope which was entirely unlike the conventional forms and primarily designed for metallographers in the study of metal structure and other objects either opaque or transparent. The instrument will handle specimens up to 50 lb. in weight and will permit magnifications ranging from 3 to 5000 diameters. In addition to visual observations the apparatus may be used for taking photomicrographs or projecting the image upon a screen for demonstration purposes.

In the Cooke Optical Comparator we find an instrument designed to supersede the use of high and low limit guages for the inspection of machine parts produced in quantities. The accuracy of a part is determined independently of the touch of the inspector it being necessary only to observe the position of a brightly illuminated line between adjustable indicators. The total magnification is 1000 and a variation of 0.0001 of an inch of the tested part from standard is represented by a movement of a tenth of an inch of the observed bright line.

Then there is the "Simplex" ripple projector which throws onto a

screen images of waves, forms and motion. Sound waves may be recorded visually through the medium of an electro-magnetic vibrator which transmits them to surface of a body of water in a glass trough. A bright light is projected through the glass bottom of the trough and passes through a lens and mirror system so that it is possible for an image of the waves or ripples on the water to be thrown on the screen. A stroboscopic disc, containing slits and rotating in the beam of light causes the ripples on the screen to appear stationary and so their forms may readily be observed. A projector of this type may be used in studying the acoustical characteristics of halls and auditoriums.

A new and remarkable invention is the " shadolite " gun which possesses all the external appearances of an ordinary rifle. However, the interior of the instrument contains a system of lenses and an ingenious mechanism whereby a luminous target is first projected upon a blank wall or upon a specially prepared target board. When aim is taken and the trigger pressed a black spot appears upon the target showing the point at which the gun was aimed and indicating the actual bullet hole had ammunition been used. Both the target and bullet mark are projected out of the barrel of the gun. Thus are eliminated all dangers, noise, fumes, and cost of ammunition while at the same time an accurate recording of the fall of every shot is secured.

Alloys of Lead and Tellurium.—(*Chem. & Ind.*, **52**, 211.) It really seems too bad that lead water pipes should be rapidly on their way to extinction just at the period when W. Singleton and Brinley Jones have made possible a pipe of lead alloyed with less than one-tenth per cent. tellurium which will withstand freezing four times as often as a pipe of ordinary lead. Lead containing from 0.02 to 0.10 per cent. tellurium becomes toughened when cold-worked. By adjustment of ralling conditions, ageing and heat-treatment, it is possible to produce metal containing not less than 99.9 per cent. of lead with a range of tensile strength from 2600 to 4000 lb./in^2. Actual exposure tests in a sulfuric acid plant showed that under the same conditions the loss in weight of the tellurium-lead was only one-seventh of that of the most resistant chemical lead hitherto known. This exceptional strength combined with increased resistance to corrosion should give tellurium-lead considerable importance in many industries where chemical sheet lead, although mechanically weak, is used because of its resistance to corrosion.

Put Surplus Eggs Down in Water-Glass Solution (U. S. Dept. of Agriculture Clip Sheet No. 770).—Fresh eggs preserved in water

glass in April and May will be good for cooking purposes up to next November or December, the United States Department of Agriculture says. Water glass is a common name for sodium silicate, which may be purchased at any drug store.

Preserve only clean, fresh, infertile eggs, the Department warns. Dirty eggs will spoil, and washing them removes the protective coating which prevents spoiling. Cracks, ever so tiny, may cause spoilage. It is a wise precaution to examine every egg by candling.

The Department gives these suggestions: Clean and scald a 5-gallon crock, allow it to dry, and place it where the eggs are to be stored. After heating a quantity of water to the boiling point let it cool, and mix the water-glass solution in the crock by adding 1 quart of water-glass to 9 gallons of water. Place the eggs in the solution as they are available. Handle them carefully to avoid cracking, and always be sure at least 2 inches of the solution covers the eggs. The crock should be kept covered, to retard evaporation. The eggs may be used at any time. If they are to be boiled, a small hole should be made with a pin in one end to prevent their cracking.

Semicentennial of the Society of Public Analysts.—This Society traces its origin to a meeting of public analysts held in London on August 7, 1874. It was formally organized on December 1, 1874, and held its first regular general meeting on February 5, 1875. Upon its incorporation in 1906, the present name The Society of Public Analysts and Other Analytical Chemists was assumed. Its early proceedings appeared in *Chemical News;* the *Analyst* first appeared in March, 1876, and has been the organ of the Society since that time, although it actually became the property of the Society in 1891. The first papers read before the Society dealt with the analysis of milk and wine, and the detection of alum in bread.

Bernard Dyer was elected to associate membership at the first regular general meeting, and was advanced to full membership the following year. In a recent book entitled "Fifty Years of the Society of Public Analysts" (published for the Society by W. Heffer & Sons Ltd., Cambridge, 1932, 278 pages), Dr. Dyer relates his reminiscences of the first half-century of the Society, carrying its history to the end of 1925.

The second portion of the book is a review of the activities of the Society during the same period, written by Dr. C. Ainsworth Mitchell, editor of the *Analyst.* These activities have been concerned primarily with the detection of adulteration in foods and drugs. Among adulterations noted during the early days of the Society were the presence of chrome yellow (lead chromate) in

sweets, the presence of chalk in oat meal, the presence of alum in flour and bread, and the presence of plaster of Paris in muffins. The major activities have dealt with foods, alcoholic and non-alcoholic beverages, condiments, food preservatives, feeding stuffs, fertilizers, water, air, drugs, and disinfectants. Other subjects have been inorganic analysis, rubber, mineral oils, cellulose and paper, and various aspects of forensic chemistry.

Scattered through this section are references to the researches of an eminent Philadelphia chemist, Henry Leffmann, and his colleagues on such subjects as honey, the occurrence of sulphur dioxide in commercial gelatin, the determination of the butter fat content of milk, the tests for boiled milk, and the influence of certain food preservatives (salicylic acid, boric acid, sulphites) and of saccharine upon the action of the enzyme diastase.

J. S. H.

Effect of Radio Vibrations on Drugs.—DAVID I. MACHT (*Jour. Am. Pharmaceutical Asso.*, 1933, XXII, 205–212) exposed 5 different drugs (benzaldehyde, tincture of digitalis, aqueous solutions of mercurochrome, cocaine hydrochloride, and eserine sulphate) to the sounds or vibrations of a radio by placing them in close proximity to the loud speaker. After such exposure for several hours, assays (physical, chemical, and biological) were made of both the exposed drugs and unexposed control samples. The specimens which had been exposed to radio vibrations had undergone more pronounced changes than their respective controls. These results are of practical importance in connection with the keeping qualities of drugs. As yet, it is uncertain which vibrations or waves, supersonic, audible sound, or mechanical vibrations, produce the changes.

J. S. H.

Atomic Weight of Lead from Cyrtolite.—GREGORY PAUL BAXTER AND CHESTER M. ALTER (*Jour. Am. Chem. Soc.*, 1933, LV, 1445–1448) have determined the atomic weight of lead obtained from the mineral cyrtolite, from Bedford, New York. This mineral is essentially zirconium silicate containing lead and uranium but no thorium. The ratio of lead chloride to silver was measured, and the atomic weight of lead calculated, and found to be 205.92 $\pm$ 0.02. Common lead was found to have an atomic weight of 207.21. Therefore, the cyrtolite or uranium lead was essentially free from common lead.

J. S. H.

Vitamin D in Poultry Husbandry.—ALLEN W. EDSON (University of Minnesota Agric. Exp. Sta. Bull. 286, 1–12, 1932) reports

that the addition of cod liver oil (preferably 2 per cent.) to the ration during the winter months increases egg production by pullets. The hatching power of the eggs is very substantially increased. These results are attributed to the vitamin D content of the cod liver oil, for similar increases in egg production and hatching power were observed when hens which had received no cod liver oil were turned out of doors and exposed to the direct sunlight regardless of whether or not they then obtained any green feed (the source of vitamin A).

J. S. H.

Loschmidt's Number. This is the number of atoms in a gram-atom or the number of molecules in a gram-molecule. S. E. VIRGO (*Science Progress*, 1933, XXVII, 634–649) has made a survey of the more than eighty different experimental determinations of this number by 21 different methods. He concludes that the most probable value is $(60.62 \pm 0.03) \times 10^{22}$.

J. S. H.

Action of Invertase at Low Temperatures.—M. A. JOSLYN AND M. SHERRILL (*Ind. and Eng. Chem.*, Industrial Edition, 1933, XXV, 416–417) have studied the influence of low temperatures upon the action of the enzyme invertase (sucrase, saccharase, invertin) which hydrolyzes cane sugar or sucrose to invert sugar, the equimolecular mixture of glucose and fructose. They used sucrose solutions having a hydrogen ion concentration of approximately pH 4.5. Invertase was added to these solutions; and they were then kept continuously at a temperature of $-12°$ to $-16°$ C., for periods ranging between 11 and 117 days. Hydrolysis of the sucrose was apparent at even 11 days, and had become quite appreciable at the end of 4 months when 0.01 milligram or more of invertase was present in each cc. of solution. The sucrose was hydrolyzed in concentrations as great as 68 per cent. As a rule, other factors being equal, the amount of hydrolysis increased with the period of storage, and with an increase in the concentration of the invertase. However, invertase in a concentration of 0.001 milligram per cc. exerted only a negligible action in all but the most dilute sucrose solutions. Practically no hydrolysis of the sucrose occurred when its solutions containing invertase were stored for 55 days at a temperature of approximately $-40°$ C.

J. S. H.

Tannin Spot Tests.—J. HAMPTON HOCH (*Jour. Am. Pharmaceutical Asso.*, 1933, XXII, 121–124) has studied the behavior of

aqueous solutions of four different tannins in concentrations ranging between 1 : 1000 and 1 : 10,000,000, with 33 reagents in spot tests on both the spot plate and filter paper. The most sensitive general reagents were ferric sulphate (5 per cent. solution), ferric acetate (1 per cent. solution), potassium dichromate (saturated solution plus a trace of acetic acid), sodium carbonate (1 per cent. solution), cupric acetate (5 per cent. solution), calcium hydroxide (saturated solution), Nessler solution, and potassium cyanide (1 per cent. solution). The reactivity of the tannin present in a dilute aqueous extract of a very fine drug powder is not significantly altered by the period of maceration within the range 5 to 30 minutes, by the temperature of the water used in maceration, or by filtration of the extract. However, solutions should be freshly prepared with distilled water.

J. S. H.

Copper Metabolism in Man.—Copper, in minute quantities, is a universal constituent of biological material. I. M. RABINOWITCH (*Jour. Biol. Chem.*, 1933, C, 479–483) has determined the daily excretion of copper through the kidney by a group of 50 individuals, who were free from undue exposure to copper due to occupation, therapy, etc. The daily excretion varied from a mere trace to 0.7 milligram of copper. In addition, the daily variation in copper excretion was observed in 3 of the subjects for a period of 10 days. The daily variations in each individual corresponded to those noted in the entire group. The conclusion is drawn that the differences between health and disease are quantitative and not qualitative so far as this mode of excretion of copper is concerned.

J. S. H.

Vitamin A Content of Naturally Colored Nut Margarines.—Margarine containing unbleached palm oil is naturally colored. CHARLES F. POE AND HAZEL A. FEHLMANN (*Ind. and Eng. Chem.*, Ind. Ed., 1933, XXV, 402–403) have assayed samples of such margarine from eight different manufacturers for their vitamin A content. The samples contained from 0.65 to 4.7 units of vitamin A per gram, hence were inferior to butter in this respect. Further experiments demonstrated that the vitamin A of the margarines was derived from their fat and not from the milk in which they had been churned in the process of manufacture. The fats used by the manufacturers were palm oil, coconut oil, cottonseed oil, peanut oil, and other vegetable oils. Of these oils, palm oil was present in each sample of margarine, and was the only appreciable source of vitamin A.

J. S. H.

New Standards for Molasses and Egg Products.—(U. S. Dept. of Agric.) The advisability of adopting new definitions and standards for molasses and for several egg products was considered by the U. S. Food Standards Committee at its April meeting held in Washington recently, according to W. S. Frisbie, Chairman. The Committee invites criticisms and suggestions on the proposals from food officials, consumers, and the trade. Communications should be addressed to the Food Standards Committee, Federal Food and Drug Administration, Washington, D. C.

The proposed definitions are:

New Orleans Molasses, Table Molasses, is the product which remains after separating sugar from the clarified and concentrated juice of sugarcane. It contains not more than 25 per cent. of water, not more than 6.5 per cent. of ash, and not less than 62 per cent. of total sugars (sucrose plus reducing sugars [1]).

Cooking Molasses is the product which remains after separating sugar from the clarified and concentrated juice of sugarcane. It contains not more than 25 per cent. of water and not less than 58 per cent. of total sugars (sucrose plus reducing sugars [1]).

Liquid Whole Eggs, Mixed Eggs, is the product obtained by separating the edible portion of eggs from the shells. It is commonly a uniform mixture of the white and yolk.

Frozen Egg is the solid product obtained by quickly and completely freezing liquid whole eggs.

Dried Egg is the product obtained by evaporating the water from liquid whole egg. It contains not more than 7 per cent. of moisture.

Egg Yolk is the product obtained by separating the whites from the yolks in the commercial process of egg-breaking. It contains not more than 12 per cent. by weight of adhering white.

Frozen Egg Yolk is the solid product obtained by quickly and completely freezing egg yolk.

Dried Egg Yolk is the product obtained by evaporating the water from egg yolk. It contains not more than 5 per cent. of moisture.

R.

Safety Glass Specifications.—(American Standards Association.) The establishment of national standard specifications and methods of test for non-shatterable and other types of safety glass will shortly be undertaken under the auspices of the American Standards Association, it was announced today (Tuesday) by Dr. P. G. Agnew, secretary of the Association.

The project, which will cover safety glass for automobiles, air-

[1] Reducing sugars calculated as invert sugar.

craft, and ships, and also bullet-proof glass and glass for industrial goggles, follows a request made by the National Bureau of Casualty and Surety Underwriters for standards which would give greater assurance that protective glasses intended chiefly to prevent unnecessary injuries and loss of life in collisions would function properly in use and not fail in crucial tests.

The actual preparation of the standard specifications and methods of test will be in the hands of a technical committee including representatives of the automobile, aircraft, and other industries, the glass manufacturers, safety organizations, insurance companies, and public regulatory bodies.

The Commonwealth of Massachusetts has already adopted specifications to which all laminated glass installed in motor vehicles registered in Massachusetts must conform. With the prospect of specifications being legally adopted by other states, the need for a national standard will become more and more pressing to prevent costly conflicting requirements in the various states.

R.

New Mold High in Fat Content.—(U. S. Dept. of Agric. Clip Sheet No. 772.) A mold which contains from 20 to 43 per cent. fat has been discovered by chemists of the U. S. Department of Agriculture. The composition of the fat is unknown; but if it has properties which ordinary fats do not have, it may have specialized uses.

The discovery was made in a routine study of molds by Department chemists. A certain percentage of fat in a mold is not uncommon, they say, but such a high percentage as was found in this particular mold, known as *Penicillium javanicum*, is unusual. The results were reported by G. E. Ward and L. B. Lockwood, of the Bureau of Chemistry and Soils, at the recent meeting of the American Chemical Society.

In their study the chemists surveyed approximately 75 molds and found 9 which contained more than 15 per cent. of fatty material. The mold producing the high percentage of fat was grown upon glucose. This mold grows larger and more rapidly than most of those studied.

Important results of other mold studies by the Department have been the development of methods of producing citric and gluconic acids.

R.

Rise of Streams Can be Predicted.—(U. S. Dept. of Agric. Clip Sheet No. 772.) The rise of the principal flood-making streams of

the United States can be predicted hours, and even days and weeks, in advance. The early spring floods in the Ohio valley this year, therefore, did not catch the country unaware. These floods were caused by two steady 48-hour downpours up the Ohio basin.

Flood forecasters of the United States Weather Bureau calculated precisely when and where the river's crest, swollen by the rain, would reach and pass the flood stage. Their reports, sent out by wire, radio, telephone, and printed bulletins, warned cities, towns, and farms of the approaching high water in plenty of time for all necessary precautions to be taken.

Luckily for the lower Mississippi valley, the Ohio usually confines its floods to January, February, and March, while most of the Missouri River floods come in May and June. Some years these two streams have gone on the rampage in April. When their floods coincide, as happened in 1927, a major disaster is likely to follow.

Contrary to the popular idea, Rocky Mountain snows play no part in Missouri River floods. Excessive rainfall is responsible for the overflow of the Mississippi and its tributaries.

There are certain types of floods that cannot be foretold. Local floods sometimes follow a sudden rainstorm so quickly and recede so fast that there is no time to receive or send reports. Nor can Federal forecasters predict floods caused by infrequent heavy rains in the Southwest. A torrent of water from such a storm may sweep through a canyon that has been dry for years and carry off buildings and other belongings before a warning can be issued.

R.

Safflower as Source of Paint Oil.—(U. S. Dept. of Agric. Clip Sheet No. 772.) Safflower seed, which yields an oil useful in paints and enamels, similar to linseed oil from flax, is being tested by the United States Department of Agriculture in the Northern Great Plains region. Although it does not advise farmers to grow safflower, because there is as yet no established market for the seed, the Department believes the crop may have possibilities and is testing it now in order to have reliable information available concerning it when its introduction can be recommended.

Safflower, which is grown in Egypt and India, grows best in the United States in the spring-wheat area of Minnesota, North Dakota, South Dakota, Nebraska, and Montana. Advocates of the crop believe that a demand for safflower seed would result in replacing some of the wheat acreage. Safflower is not intended to replace flax but as a possible supplement to it. In normal times flax production in the United States is about half of the national consumption.

Weathering and other tests are being made with paint and enamel in which safflower oil has been used. While manufacturers carry on this work, the Department is continuing its field tests of safflower. The crop is grown to a limited extent at Federal and State experiment stations and some farmers coöperate in making experimental tests. The Department grows it to learn the best methods of handling it and to keep up a seed supply.

Safflower can be handled with the machinery ordinarily used in small-grain farming. It is especially easy to harvest with a combine as it can stand in the field some time after ripening without shattering or lodging.

R.

Power Resources of Tennessee River Basin.—(U. S. Geol. Survey.) Statistics collected give the following information in regard to the power resources of the Tennessee River Basin:

The total water-power resources of the basin are about 3,000,000 horsepower available 50 per cent. of the time, or about 2,500,000 horsepower available 90 per cent. of the time. On the basis of the present practice in the installation of water wheels at developed water-power plants, about 5,000,000 horsepower of water wheels would be required in the development of all the water-power resources of the Tennessee River Basin. The total capacity of the 46 water-power plants in the basin that have 100 horsepower or more at present is 876,000 horsepower; therefore less than 20 per cent. of the total water-power resources of the basin is developed.

The primary use of water power in the basin is in the generation of electricity for light and power. About 700,000 horsepower is used to drive the generators of public-utility plants, and about 175,000 horsepower is used by manufacturing plants, many of which generate electric power for their own use. The following table shows the total number of public-utility plants in the basin, the capacity of the generators driven by water power, by steam

Public-Utility Power Plants in the Tennessee River Basin in 1932.

Number	Kind	Total capacity		Production of electricity	
		Kilowatts	Per cent. of total	Kilowatt-hours	Per cent. of total
31	Hydro	513,130	77	1,142,763,000	98
16	Steam	150,747	23	27,484,000	2
8	Internal combustion	3,120	—	1,841,000	—
55		666,997	100	1,172,088,000	100

power, and by internal-combustion engines, and the amount of electricity generated by the use of water power and by the use of fuels.

The electricity generated by public-utility power plants is distributed over the basin by means of transmission lines with a total length between 3,000 and 4,000 miles.

The principal uses of power at the present time are about as follows:

	Per cent.
Lighting and domestic	43
Cement, clay products, ore, mines and quarries	11
Electrochemical foundries, boiler and machine shops	20
Enamelware, agricultural implements, furniture, and paper	6
Textile mills	6
Food and dairy products and ice plants	4
Miscellaneous	10
	100

Increase in the demand for power will come through increased urban and rural domestic use, the development of industries in the States composing the basin and in the surrounding States, and the electrification of railroads where traffic conditions will justify the cost. In all three lines there are large possibilities, which depend upon the wise development and proper use of the natural resources that are so abundant in the basin.

R.

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